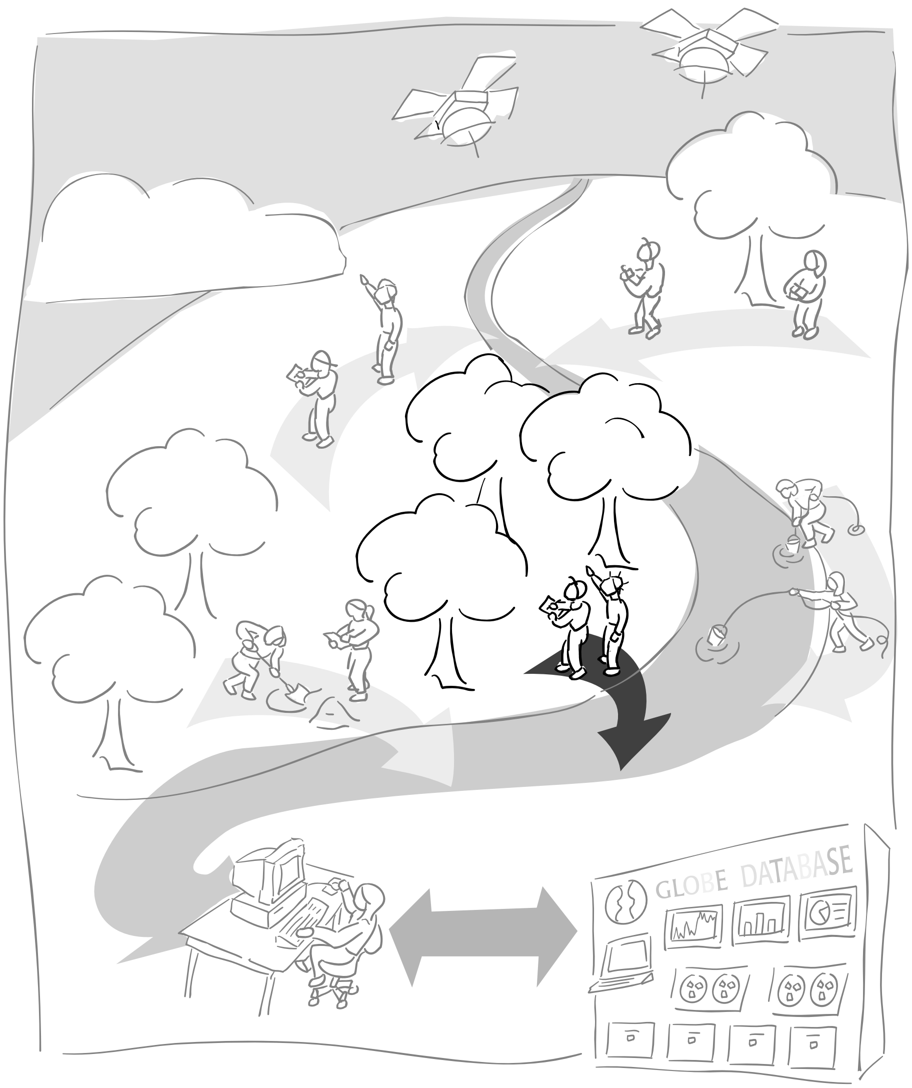
Land Cover/Biology Investigation



A GLOBE® Learning Investigation

Land Cover/Biology Investigation at a Glance

Protocols

Land Cover Sample Site Protocol
Data collected once for each site: GPS location, photographs, land cover classification.

Biometry Protocol
Data collected once to determine land cover class of Land Cover Sample Sites or more often to study changes in biomass over time: canopy cover and ground cover, tree, shrub and/or graminoid height, tree circumference, graminoid biomass, dominant and co-dominant vegetation.

Manual Land Cover Mapping Protocol and Computer-aided Land Cover Mapping Protocol
Perform once to create a land cover type map of your GLOBE Study Site and then update as desired.

Land Cover Change Detection Protocol
Perform once to create a map that illustrates changes that have occurred over time (period of a few years) in your GLOBE Study Site.

Suggested Sequence of Activities

Note: Certain Learning Activities are desirable prior to implementing Protocols.

Read the *Introduction*, especially *Measurement Logistics* and *Suggested Methodology*.

Perform *Getting to Know Your Satellite Imagery and GLOBE Study Site Learning Activity.*

Make a densiometer and clinometer (see *Investigation Instruments*).

Review how to pace and use a compass, densiometer, clinometer and tape measure (see *Investigation Instruments*).

Practice the *GPS Protocol* (see *GPS Chapter)* and the *Biometry Protocol*.

Choose appropriate Land Cover Sample Sites within your Study Site (review *Sample Site Selection and Set-up)*.

Perform the *Site Seeing Learning Activity* - introduces systems concepts.

Perform the *Leaf Classification Learning Activity* - introduces the concepts of classification.

Practice using the MUC System to classify land cover.

Perform *Land Cover Sample Site Protocol* at each Sample Site.

Perform the *Odyssey of the Eyes Learning Activity* - introduces remote sensing.

Perform either M*anual Mapping: A Tutorial for the Beverly, MA Image* (from the *Appendix)* if you will be doing a manual map or the *Unsupervised Clustering Tutorial* (from the MultiSpec CD) if you will be doing a computer-aided map.

Perform either *Manual* or *Computer-aided Land Cover Mapping Protocol* using your GLOBE Study Site satellite image.

Perform the *Bird Beak Accuracy Assessment Learning Activity* - introduces accuracy assessment.

Perform the *Accuracy Assessment Tutorial* from the *Appendix* to analyze the accuracy of your land cover type map.

Perform the *Land Cover Change Detection Protocol.*

Perform the *Discovery Area Learning Activity* - uses the satellite images and maps students create.

Using GLOBE Data to Analyze Land Cover Learning Activity - relates land cover data to other GLOBE investigation measurements.

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* See the full e-guide version of the *Teacher's Guide* available on the GLOBE Web site and CD-ROM.

Introduction

The Big Picture

Earth's surface is two-thirds water. The continents on which we live make up the remainder. Until the launch of the first humans into space, we did not fully appreciate the beauty and diversity of our planet. We rely on Earth's surface (and a little bit above and below) to supply most of what we need to live. Therefore, mapping and monitoring this surface is critical to our wise use and protection of it.

Remote sensing simply means learning something about an object without making direct contact with it. We use remote sensing every day by hearing, smelling, and seeing. Historically we have used aerial photographs taken from balloons, airplanes, and more recently, digital images acquired by orbiting satellites, to map and monitor Earth's land cover.

Remote sensing from space has the great advantages of being able to cover very large areas quickly and to revisit the same area frequently. However, some of the detail that can be seen at ground level may not be detected by a remote sensing system. Therefore, it is beneficial to collect data at sample sites on the ground to accompany remotely sensed data about an area. It is not possible to effectively visit every place on Earth to map the land cover. Instead, we rely on samples – actual ground visits – and relate these samples to what we can see using various remote sensing systems.

Remote sensing observations of the land surface are usually presented as digital images. Each element of such an image is a *pixel* or picture element. The size of the pixels depends on the spatial resolution of the remote sensing instrument. Spatial resolution refers to the size of the smallest object or area that can be distinguished from its surroundings. The Landsat Thematic Mapper (TM) imagery used in the GLOBE Program has a spatial resolution or pixel size of 30 m x 30 m. See Figure LAND-I-1.

Spectral resolution refers to the wavelengths of light, commonly called bands, the satellite image sensors are capable of measuring. Our eyes also sense different wavelengths of light (colors), but we only see in a range of wavelengths known as the visible portion of the spectrum. The new Landsat 7 Enhanced Thematic Mapper is capable of sensing six bands – blue, green, red, near infrared and two mid-infrared, – at 30 m x 30 m spatial resolution. It also senses one band in the thermal infrared at 60 m x 60 m spatial resolution and one panchromatic band covering wavelengths from blue to near infrared at 15 m x 15 m spatial resolution. In GLOBE, we make use of five of the first six bands, which are the same as those available from earlier Thematic Mapper instruments. For more information on remote sensing, refer to the *Remote Sensing* section of the *Implementation Guide.*

Remote sensing scientists use satellite images as tools to help make maps of land cover types. An important issue that arises is, "How good are the land cover maps made from remotely sensed data?" The way to answer this question is to conduct an accuracy assessment of the remotely sensed map. If appropriate sample land cover sites are visited on the ground, then these samples can be compared to the same areas on the map and a measure of map accuracy determined. In this way, we can evaluate how good our land cover maps are. This assessment is very useful when it comes to making important decisions about Earth's land cover from these maps.

Finally, it is important that the ground samples and the remote sensing maps use the same classification system. A classification system consists of a list of labels or land cover types and the corresponding definitions for each label. Since the GLOBE Program is a world-wide effort, it is important that the classification system chosen be appropriate for any place on Earth. In the GLOBE Program, we have modified a widely accepted system developed by UNESCO (United Nations Educational, Scientific and Cultural Organization) to include both natural and developed land cover. This system is called the Modified UNESCO Classification (MUC) System. Everyone in the GLOBE Program uses MUC to label sample sites visited on the ground as well as the maps made from the remotely sensed data. Therefore, a consistent and uniform land cover map can be created for the entire world and validated.

Why Investigate Land Cover?

Land cover is a general term used to describe what is on the ground or covering the land. Different land cover terms are used to describe the differences we see when we look at the land. Land cover can include where we live (in houses or apartments), where we do business and produce goods and services (commercial and agriculture areas) and how we travel (on roads, trains, and from airports). It is also a term that is used to describe different natural habitats; desert, forest, woodland, wetland, glaciers and water bodies, among others. All living things depend on their habitat, their land cover, for survival. They find shelter there, they find food there, and they find protection there. Land cover has a direct effect on the kinds of animals that will likely inhabit an area. Therefore, land cover is of great interest to ecologists, who study how plants and animals relate to their environment.

Land cover can influence weather, soil properties, and water chemistry. Different land cover types are all distinct in their effects on the flow of energy, water and various chemicals between the air and surface soil. Natural land cover, meaning land cover that is not the result of human activity, is often an indication of the climate of an area. For instance, forests may be found on the wet side of a mountain while in the rain shadow on the other side there may be shrubland. In a coastal region with frequent fog, the plants that grow there modify the soil over time. The land cover in such an area is a community of trees, shrubs, and other plants indicative of a foggy coast. Large rainforests actually create their own weather with daily rain showers. In deserts, plants adapted to dry conditions dominate the land cover.

Knowing the type of land cover in a region helps us understand the local climate. For scientists studying atmosphere, soil and hydrology, the type of land cover surrounding measurement sites is an important piece of information. This type of information is often referred to as *metadata* and helps provide a context for evaluating data collected by the scientists or students on that site. However, for land cover scientists, land cover data provide much more than that.

Mapping

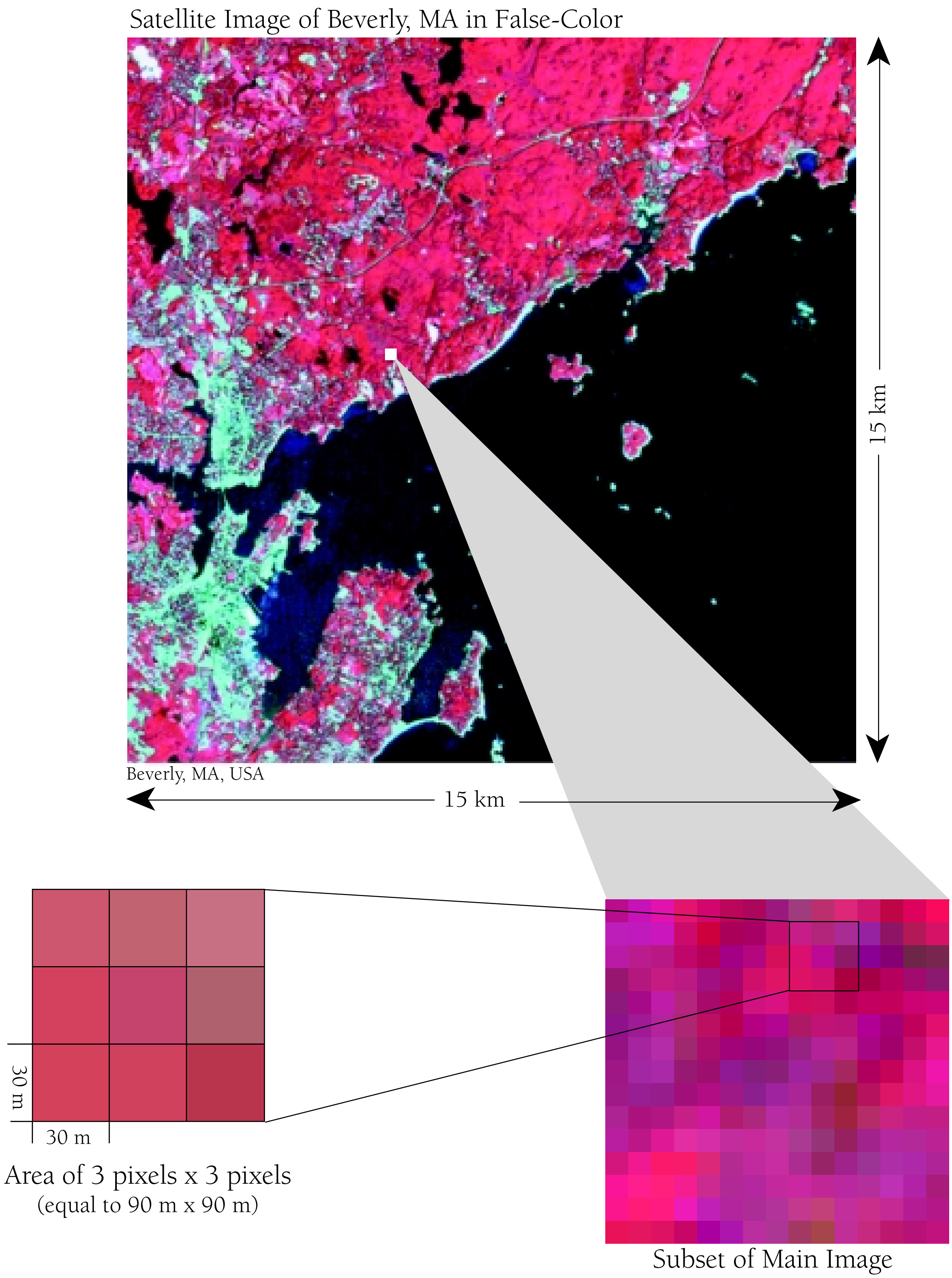
Data collected at land cover sample sites visited on the ground help land cover scientists to create and label land cover maps produced from satellite images and aerial photographs. Additional independent ground sample sites help verify how accurate these maps are. Data from ground sample sites such as detailed biometric observations (measurements of living things) help Earth systems scientists improve their ability to interpret satellite imagery.

Monitoring

Land cover maps are used to monitor endangered plants, animals and habitats, economic development, land use, fire fuel management, cropland management, wetland loss, effects of environmental change in ecosystems and other changes in land cover over time. The list of uses is long once scientists have access to accurate and precise land cover data.

Biometry data collected in the field assist scientists in monitoring the amount of nutrients, water and gases in vegetation. This is helpful in understanding Earth systems, including; nutrient cycles, the energy cycle and the hydrological cycle. Land cover influences these cycles in a variety of ways. One example is how solar radiation, reflected by land and vegetation, affects regional and global climate patterns. Since land cover is a component of numerous systems, monitoring its characteristics will provide more information for understanding global ecological systems. Plants are part of nutrient cycles and hydrological cycles and they can be used as indicators to monitor changes in these systems. Remotely sensed data that discriminate between various kinds of vegetation may be used to determine health and density of plants, but require ground observations to quantify and calibrate these relationships.

Figure LAND-I-1: Example Satellite Image



As you zoom in on a 15 km x 15 km satellite image, the pixels (which are 30 m x 30 m in size) become visible. In the *Land Cover/Biology Investigation,* students take field measurements at sites that are 90 m x 90 m (equal to 3 pixels x 3 pixels).

Scientists Need GLOBE Data

Scientists collect ground data to learn as much about Earth as they can. Ideally, Earth systems scientists would like to have information about every place on our planet. The more ground data the better. Practically, it is only possible to collect this information for a small sample of areas. Remote sensing provides a means of relating observations and measurements on the ground to the larger regional and global views. Ground data are needed to learn about sample areas and to validate (i.e., compare with) the maps generated from remotely sensed data. At a GLOBE school, students can significantly add to our limited supply of ground information. No other group in the world is collecting a uniform data set such as this. Therefore, GLOBE schools are providing unique, valuable information that will help scientists to better understand Earth. Through the *Land Cover/Biology Investigation Mapping* and *Data Collection Protocols,* GLOBE students will significantly help Earth systems science while increasing their own knowledge and understanding of the scientific process, ecological systems and their surrounding landscape.

Educational Objectives

Students participating in the activities presented in this chapter should gain scientific inquiry abilities and understanding of a number of scientific concepts. These abilities include the use of a variety of specific instruments and techniques to take measurements and analyze the resulting data along with general approaches to inquiry. The Scientific Inquiry Abilities listed in the grey box are based on the assumption that the teacher has completed the protocol including the Looking At the Data section. If this section is not used, not all of the Inquiry Abilities will be covered. The Science Concepts included are outlined in the United States National Science Education Standards as recommended by the US National Research Council and include those for Earth and Space Science, Physical Science, and Life Science. The Geography Concepts are taken from the National Geography Standards prepared by the National Education Standards Project. Additional Enrichment Concepts specific to the land cover measurements and mapping have been included as well. The gray box at the beginning of each protocol or learning activity gives the key scientific concepts and scientific inquiry abilities covered. The following tables provide a summary indicating which concepts and abilities are covered in which protocols or learning activities.

	Basic Protocols		
National Science Education Standards	Sample Site	Biometry	Manual Map.
Physical Science Concepts			
Properties of Objects and Material (K–4)			
Objects have observable properties	■	■	
Position and Motion of Objects (K–4)			
Position of objects can be described by locating it relative to another object	■		
Life Science Concepts			
The Characteristics of Organisms (K–4)			
Earth has many different environments that support different combinations of organisms	■	■	
Organisms and their Environments (K–4)			
Organisms' functions relate to their environment			
Organisms change the environment in which they live		■	
Humans can change natural environments			
Structure and Function of Living Systems (5–8)			
Ecosystems demonstrate the complementarity nature of structure and functio			
Regulation and Behavior (5–8)			
All organisms must be able to obtain and use resources while living in a constantly changing environment			
Populations and Ecosystems (5–8)			
All populations living together and the physical factors with which they interact constitute an ecosystem	■	■	
The Interdependence of Organisms (9–12)			
Humans can change ecosystem balance			
Geography Concepts			
How to Use Maps (real and imaginary (K–4))	■		
The Physical Characteristics of Place (K–4)	■	■	
The Characteristics and Spatial Distribution of Ecosystems (K–12)	■	■	■
How humans modify the environment			■

Advanced Protocols		Learning Activities						
Computer-Aided Mapping	Land Cover Change	Getting to Know	Site Seeing	Leaf Classifi-cation	Odyssey	Bird Beak Accuracy	Discovery Area	Using GLOBE Data
				■		■		
	■		■				■	
	■					■		
	■	■						
							■	
	■							
■	■		■		■			■
	■						■	
	■	■	■		■			■
	■	■	■		■			■
■	■	■	■		■			■
■	■		■		■		■	■

	Basic Protocols		
National Science Inquiry Standards	Sample Site	Biometry	Manual Mapping
General Scientific Inquiry Abilities			
Use appropriate tools and techniques			
Construct a scientific instrument or model			
Identify answerable questions	■	■	■
Design and conduct scientific investigations	■	■	■
Use appropriate mathematics to analyze data	■	■	■
Develop descriptions and explanations using evidence	■	■	■
Recognize and analyze alternative explanations	■	■	■
Communicate procedures and explanations	■	■	■
Specific Scientific Inquiry Abilities			
Use appropriate field instruments and techniques to gather Land Cover sample	■		
Make observations in order to determine the appropriate land cover type	■		
Communicate the results of land cover classification to reach a consensus	■		
Identify biometry measurements needed for MUC		■	
Use vegetation field guides to identify vegetation and species		■	
Interpret data to propose MUC classification		■	
Classify land cover and create a land cover type map			■
Evaluate how accurate the land cover map type is using accuracy assessment			■
Use land cover data and appropriate tools and technology to interpret change			
Gathering spatial data and historical data to determine validity of change hypotheses			
Use maps, aerial photographs and other tools and techniques on order to create a land cover map			
Recognize and analyze differing viewpoints on land cover classification and reach a consensus			
Integrate data from variety of different data sets to gain dynamic understanding of how earth system works			
Classification helps organize and understand the natural world			
A classification system is a system of labels and rules used to sort objects			
A hierarchical system has multiple levels of increasing detail			
Observe a landscape and design a model of it			
Draw a landscape from various perspectives			
Use different scales to view a group of objects			
Identify decision criteria for a classification system, and use it to classify birds			
Collect and interpret validations data			
Use numerical data for in describing and comparing the accuracy of the classification			
Use the land cover type map to discuss how a structure will affect organisms using a particular land cover type			
Analyze different scenarios that change the land cover types of an area			
Evaluate different solutions to various scenarios			
Use GLOBE Website to gather, analyze and interpret data			

Adv. Protocols		Learning Activities						
Computer-Aided Mapping	Land Cover Change	Getting to Know	Site Seeing	Leaf Classifi-cation	Odyssey	Bird Beak Activity	Discovery Area	Using GLOBE Data
■	■	■	■	■	■	■	■	■
■	■	■	■	■	■	■	■	■
■	■	■	■	■	■	■	■	■
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Measurement Logistics

Overview

This Investigation will involve studying the land cover in your GLOBE Study Site, a 15 km by 15 km area centered around your school. Within this Study Site, you will visit various Land Cover Sample Sites to collect data about the type of land cover present. Each of these Sample Sites must be 90 m X 90 m in size and have the same land cover type throughout. GLOBE provides the imagery of your Study Site. As you build an understanding of the land cover in your area, you will create a land cover type map from the satellite imagery. Ultimately, changes over time in land cover are studied through a comparison of two co-registered satellite images of your GLOBE Study Site and the accompanying ground measurement data that you have collected. The images are acquired a few years apart and you can compare the changes that occur between the two dates.

Where are measurements taken?

Your *Land Cover/Biology Investigation* measurements are taken in your GLOBE Study Site. This is the 15 km x 15 km area, with your school near the center, defined by the Landsat Thematic Mapper (TM) satellite imagery provided to you by GLOBE. For information on obtaining this imagery, contact your Country Coordinator, US Partner, or the GLOBE Help Desk. By performing the protocols and learning activities associated with this investigation, you and your students will become intimately familiar with this part of our global environment. Together, you will create and validate a land cover type map of this area.

Within your GLOBE Study Site, it is important that you select appropriate ground sites (called Land Cover Sample Sites) for observation and detailed measurements. See Figure LAND-I-1. You should have at least one Land Cover Sample Site for every type of land cover that exists in your Study Site. These Sample Sites are areas of homogeneous land cover (the same land cover type throughout) at least 90 m x 90 m in size. If you are in an area of homogeneous land cover that is larger than 90 m x 90 m, locate your Sample Site toward the center of the area. See Figure LAND-I-2. A Sample Site area of 90 m x 90 m is necessary in order to accurately locate the site on the ground and on the satellite imagery. This area is equivalent to 9 Landsat Thematic Mapper (TM) pixels (a square of 3 pixels by 3 pixels). See the *Remote Sensing* section of the *Implementation Guide*.

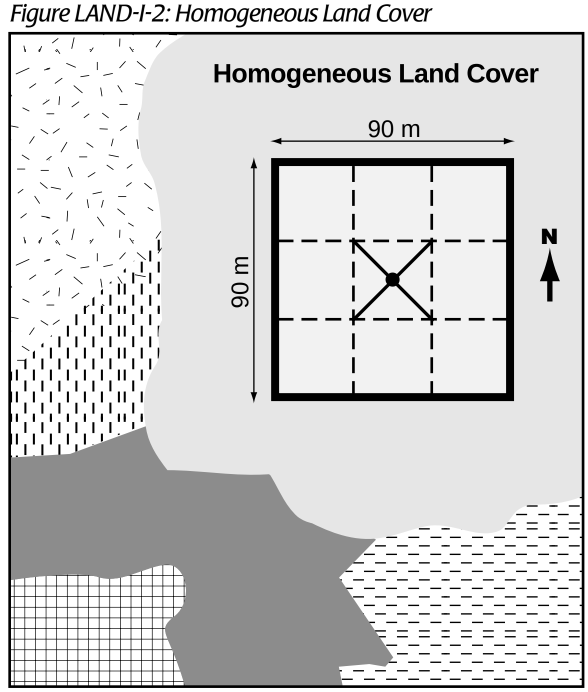
You may collect data from areas outside your GLOBE Study Site as well. For instance, some schools make periodic visits to remote natural sites such as national parks. They collect data while on these field trips and report their measurements to GLOBE. If your school will make repeated visits to such a remote location, you should request Landsat image products for this site from GLOBE so that you can do all aspects of the *Land Cover/Biology Investigation* for this additional area.

What measurements are taken?

There are two varieties of land cover measurements reported to GLOBE. The first involve observations taken at each of your Land Cover Sample Sites. The second involve land cover type maps that you make of your GLOBE Study Site.

The *Land Cover Sample Site Protocol* details the steps for taking measurements at a Land Cover Sample Site. There are three essential observations:

Figure LAND-I-2: Homogeneous Land Cover



- Latitude, longitude and elevation using a GPS (Global Positioning System) receiver.
- Land cover classification (using the MUC System, GLOBE's land cover classification system).
- Photographs taken in the four cardinal directions (N, S, W, and E) from the center of the site.

To determine the land cover classification you may need to take additional measurements. The amount of measurements will vary depending on the nature of the land cover at the site. Classifying a site can take from 20 minutes to approximately an hour, depending on which measurements you must take. In addition to the measurements from the *Land Cover Sample Site Protocol*, you may include quantitative measurements of the mass of plant matter present, known as biometry measurements. The *Biometry Protocol* outlines the steps to take these measurements, which include canopy and ground cover, tree, shrub and/or graminoid height, tree circumference and graminoid biomass. **All relevant Biometry measurements should be taken in order to determine and/or verify the correct land cover class.** These measurements are used to study vegetation growth and change. Throughout your investigation, you will collect and report data from a variety of Sample Sites.

As part of the *Land Cover/Biology Investigation,* you will also generate land cover maps of your Study Site. You will create a map of land cover type either by hand following the *Manual Land Cover Mapping Protocol* or through the use of MultiSpec software following the *Computer-aided Land Cover Mapping Protocol*. The culmination of your investigation will involve comparing satellite images acquired a few years apart to study land cover change over time by following the *Land Cover Change Detection Protocol*. For the mapping protocols, the final map product is the data reported to GLOBE and this is done at the end of the mapping process. These maps are created to learn more about your surroundings by taking observations and measurements at selected sample locations. Upon completing this investigation, you will know a great deal about the environment surrounding your school and you will be able to monitor change as it happens. For your school, these protocols can last from one day to weeks to months to years. Please refer to the specific section on the *Mapping and Accuracy Assessment Process* for more details.

When are measurements taken?

The best time to take the measurements for the *Land Cover Sample Site* and *Biometry Protocols* is during the peak of the growing season. This is when it is best to assess the land cover class of the site and the full canopy and ground cover. If you are going to visit a site repeatedly and take biometry measurements to monitor changes in biomass over time for a period of years, you can visit the site once every year at the same time of year. Or, if you would like to track changes in biomass throughout the year, you many choose to visit a site twice a year or more, once during the peak of the growing season and once during minimum growth (ex. dry season or winter). The mapping protocols can be performed at any time of year.

Special Considerations

A number of time management, educational, and logistical issues should be considered in deciding how to present and undertake the various *Land Cover/Biology Protocols.*

- Land cover data can be collected from all land cover classes as long as the sites are homogeneous and at least 90 m x 90 m in size.
- Biometry measurements in Land Cover Sample Sites are very useful and offer students a more complete view of the land cover assessment process. They are used to decide the correct land cover class for a Land Cover Sample Site.
- Land Cover Sample Site observations are useful and can be quickly and efficiently collected in sufficient number to validate (or assess the accuracy of) your land cover type map generated from the Landsat Thematic Mapper imagery.
- Students benefit from practicing biometry measurements before going to their Land

Cover Sample Sites. Practice, before going into the field, can lessen the amount of time it takes to collect the observations at the site.

- If a GPS receiver and a camera are available, observation of a Land Cover Sample Site can be accomplished quickly. If they are not, you will have to return to the site to complete the observations. It would be to your benefit to have these with you in the field.
- Schools should collect as many Land Cover Sample Sites as possible for each land cover type present on their land cover type map because many samples are needed to assess the accuracy of the map. Sites collected in different years, by different classes, or even neighboring schools can all be used in the accuracy assessment process.
- Be sure to note the difference between naturally vegetated sites and cultivated sites.
- Review the *Glossary of Terms* to make sure that you understand the terms used throughout this Investigation.

Getting Started

Using the *Land Cover/Biology Protocols,* you and your students can explore the land cover in your GLOBE Study Site and answer questions that are relevant to your particular area, region and/or students. Land cover map creation is just one step for scientists. Once they have created this map, they can use and modify it in order to study a specific question they are researching. For instance, scientists may be studying the habitat of a certain animal or plant, the succession of fields to forests or the rate of growth of a particular village, town or city. They may also be looking at the amount of undeveloped land, how to protect water resources, or where to plant certain crops during the next growing season. Town planners may be interested in creating a map in order to decide new school boundaries, where to connect recreational trails to create one continuous system or how to efficiently run public transportation. These are just some possible uses of your maps. By creating a base map, you and your students have a powerful tool to begin to look at what your students feel is important in their particular area.

There are many ways to begin your investigation of land cover. One of the simplest and quickest is to use the learning activity, *Getting to Know Your Satellite Imagery*. It is an exploration of the imagery. From there, you and your students can begin to notice the "pattern" of land cover in your area. This may bring up community issues that interest your students – water bodies that need protection, land that is being eroded, a trail system that can be connected to other systems, etc. Beginning with these ideas, introduce the protocols as a way to explore these issues further. The student introduction page for each of the protocols offers some questions that your students should be thinking about to be in the correct "mindset" for that protocol. It introduces the kind of data they will be collecting, asks students to think about why they are collecting that particular data, and then asks them how they can apply it to their own questions. By beginning with the learning activity or the protocols themselves, the *Land Cover/Biology Investigation* leaves it to your students to choose what particular part of their environment they want to explore. If your students are hesitant about generating their own questions or do not have an idea where to begin, just collecting the Land Cover Sample Site data and working on the land cover map is a great start, and may help them to come up with their own questions. The *Land Cover Change Detection Protocol* also can serve as a basis for the question: What amount of change has taken place in my GLOBE Study Site between the years of the two images?

Feel free to start with as little or as much data collection as is comfortable. One Land Cover Sample Site is a start. Multiple sites can be collected the next year, once you and your students get accustomed to the process. If you and your students are ready to explore the area surrounding your school, begin the *Land Cover/Biology Investigation!*

Protocols At A Glance

PROTOCOL	What procedures are performed?	Where are procedures conducted?	When are procedures conducted?	What equipment is needed?
Land Cover Sample Site	MUC, latitude, longitude, elevation, photographs	In a 90 m x 90 m homogeneous area	Once for every new site during peak growing season, or more frequently in sites of your choosing	*MUC Field Guide* or *MUC System Table and MUC Glossary of Terms,* GPS, camera, compass, biometry equipment
Biometry	Canopy cover, ground cover, tree, shrub and graminoid height, tree circumference, graminoid biomass	At Land Cover Sample Sites	To determine MUC or to supplement the observations at a site	Densiometer, clinometer, measuring tapes, Vegetation Field Guides, grass clippers, *MUC Field Guide* or *MUC System Table and MUC Glossary of Terms*, GPS, camera, compass
Manual Land Cover Mapping	Manually create a land cover type map	In class, for entire GLOBE Study Site	Once, but may be an iterative process as new sites are added	Landsat TM images, transparencies, markers, *MUC Field Guide* or *MUC System Table* and *MUC Glossary of Terms*
Computer-aided Land Cover Mapping*	Digitally create a land cover type map	On computer, for entire GLOBE Study Site	Once, but may be an iterative process as new sites are added	Computer, Landsat TM data on disk, MultiSpec software, *MUC Field Guide* or *MUC System Table* and *MUC Glossary of Terms*
Change Detection*	Create a land cover change map	On computer, for entire GLOBE Study Site	Once, but may be an iterative process as new sites are added	Computer, Landsat TM data on disk for two different time periods, MultiSpec software

* See the full e-guide version of the *Teacher's Guide* available on the GLOBE Web site and CD-ROM.

Suggested Methodology

The following flow diagrams (Figure LAND-I-3, Figure LAND-I-4) present the methodology to conduct the *Land Cover/Biology Investigation*. The investigation focuses on determining and mapping the land cover for a particular area, the GLOBE Study Site, and monitoring it for changes over time. This flow diagram is divided into two parts. The first part outlines the land cover data collection methods and the second part shows the land cover mapping and change detection procedures. Italics indicate the protocols within the flow diagram. All these measurements can be used to improve our understanding of the cycling of energy, water and chemical elements such as carbon and nitrogen. The land cover maps students make of their GLOBE Study Site and maps of larger areas created by scientists can be used for management, research, and student inquiry. How and where are land cover types changing? Are there differences in soil fertility between the soil under a deciduous forest and a wetland? What happens to the water chemistry when the surrounding land cover changes? These and many other questions are best answered with the help of accurate land cover maps and field measurements.

Data Collection

To begin the *Land Cover/Biology Investigation* you need to become familiar with your GLOBE Study Site by examining the Landsat Thematic Mapper (TM) satellite image and any other maps or photos of the area that you can obtain. Along with examining the imagery, sites on the ground should be explored to begin to understand the various types of land cover within the 15 km x 15 km GLOBE Study Site. Once you gain some familiarity with the GLOBE Study Site, select homogeneous areas (the same land cover type throughout) for collecting Land Cover Sample Site data. Before going to sites, students should have an

Figure LAND-I-3

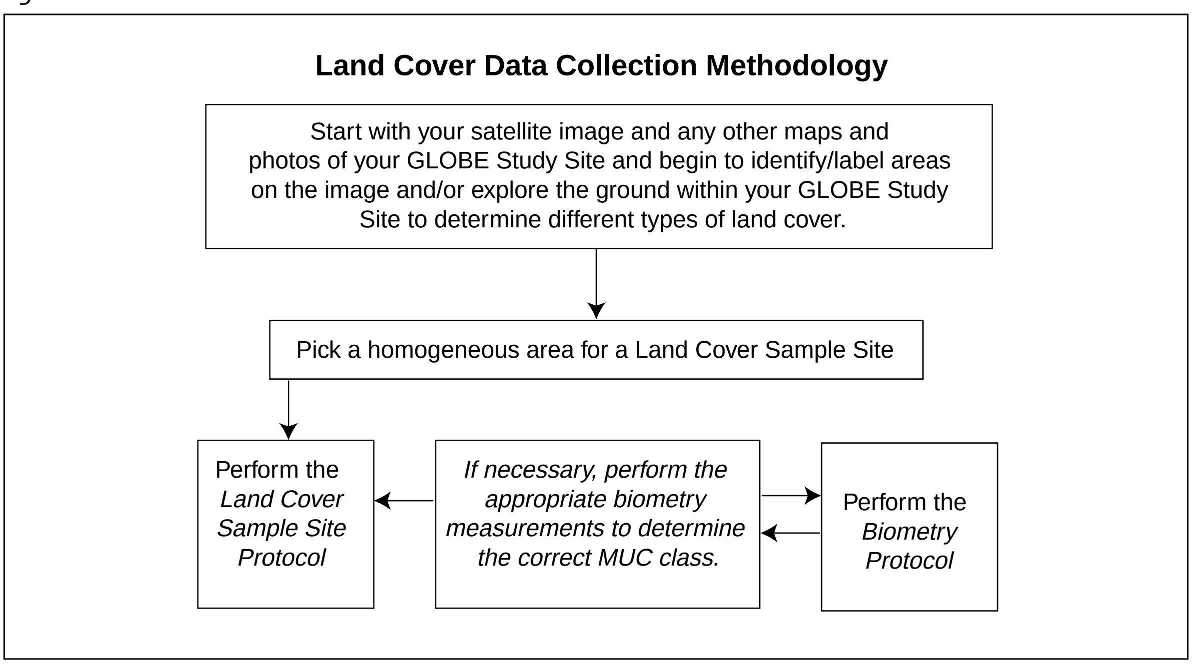
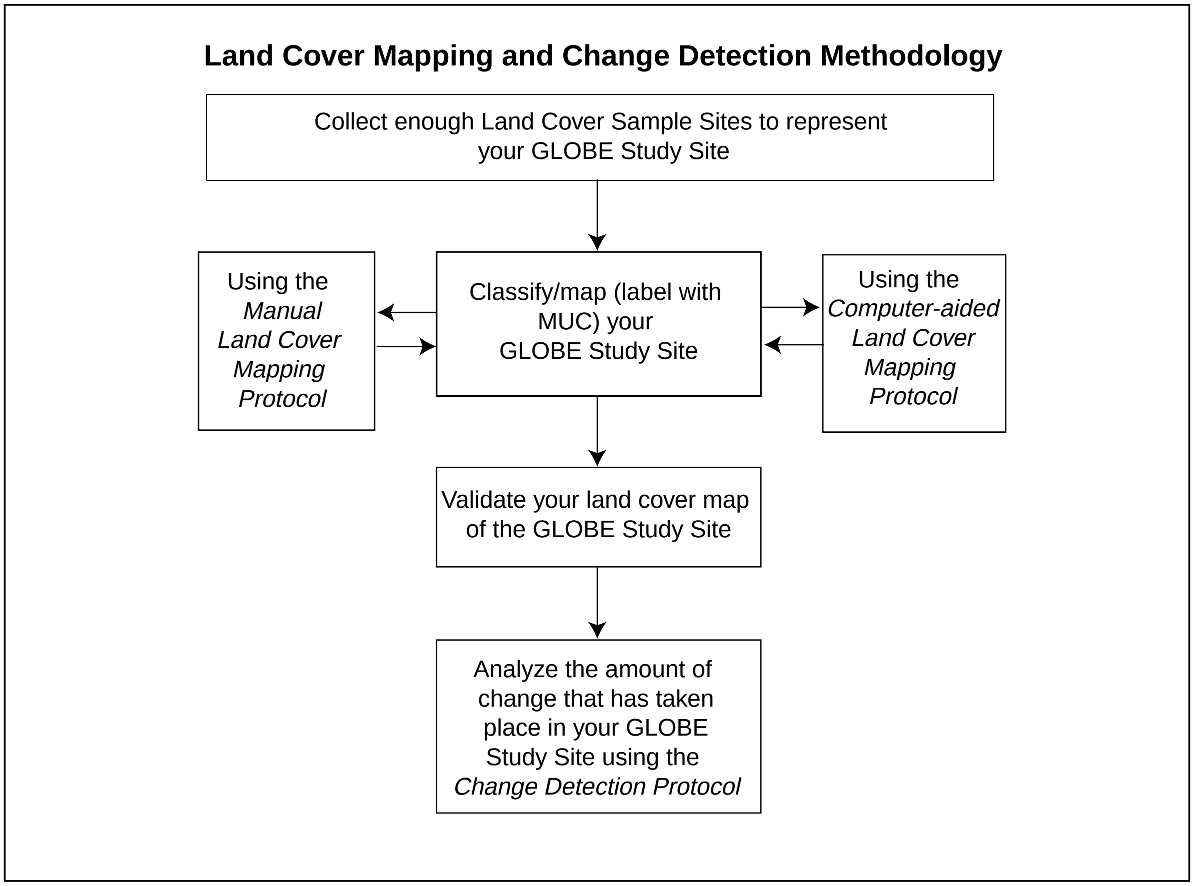


Figure LAND-I-4



understanding of the land cover classification system used in GLOBE, the MUC System, and how the biometry measurements can be used to help determine the MUC class. Also, be sure that you have all the necessary equipment to carry out the field measurements. You will make a few key pieces of equipment yourself following directions in the *Investigation Instruments* section of this chapter. You should also have enough copies of the *Field Guides* for taking the measurements (found in the *Protocols*) and the corresponding *Data Sheets* (found in the *Appendix*). Students who practice the biometry measurements before field collection carry out the measurements more efficiently and accurately in the field. Once a homogeneous sample site has been chosen, the MUC System understood, you have constructed your instruments, made the necessary copies of field guides and *Data Sheets*, and practiced the *Biometry Protocol*, you are ready to establish a Land Cover Sample Site.

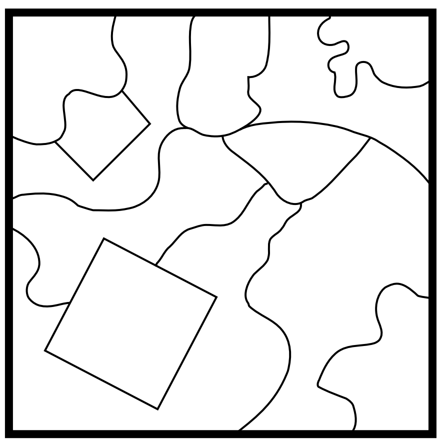
It is highly desirable for you and your students to collect data for several Land Cover Sample Sites in each of the major types of land cover identified within your GLOBE Study Site. You should also collect as much biometry data as needed at each Land Cover Sample Site to accurately classify the site using the MUC System. Start with the most common types of land cover, and continue to add sample sites until you have collected data for as many of the land cover types as you can. Doing this investigation is made easier if your students have a GPS receiver with them when they are at each site. This way, they do not have to return to the site later, find the center and take measurements on another trip.

Biometry data should be collected at Land Cover Sample Sites that are visited once in order to determine the MUC class. The amount of biometry data collected will vary but you can always collect more data to supplement the information about the site. It is desirable to take the full set of biometry measurements at one site that is representative of each forest, woodland and graminoid (grassland) MUC class found in your area. Biometry data can also be collected at sites that you visit more frequently. Some schools choose one site which they visit every year at the same time of year to record changes in biometry over time. Other schools choose to visit a single site twice a year in order to track seasonal changes. Often, their visits will correspond to the times of peak foliage and minimum foliage (drought or winter season). In summary, at a minimum, collect biometry measurements at each site to help you determine the MUC class. The maximum amount of data you collect is your class' decision and should be based on what kind of changes you are monitoring in your site. All land cover data collected accurately by GLOBE students will be useful. GLOBE scientists recognize that logistics and educational concerns will usually dictate what land cover measurements are taken.

Land Cover Sample Sites are important for validating the accuracy of land cover type maps, which is a key scientific objective of this investigation. It is recognized, however, that it will take time, perhaps several successive years, to accumulate a set of Land Cover Sample Sites representative of each important type of land cover within your GLOBE Study Site. You may want to assign a land cover type to each of several student teams, so that no two teams are working in the same type of land cover and as many data are collected as possible.

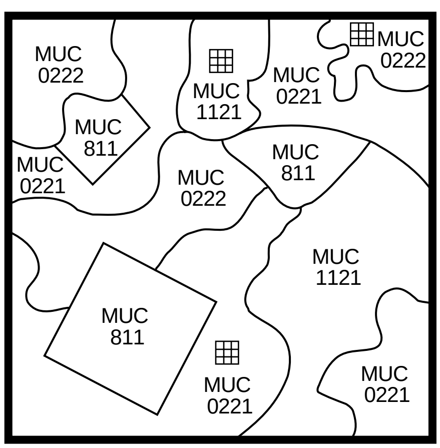
Figure LAND-I-5: Diagram of Accuracy Assessment Process

Step 1: Manual or Computer-aided Land Cover Mapping



The Landsat TM image of your GLOBE Study Site is divided into areas of similar land cover type manually or using MultiSpec.

Step 2: Assign MUC Classes to Areas (Clusters)

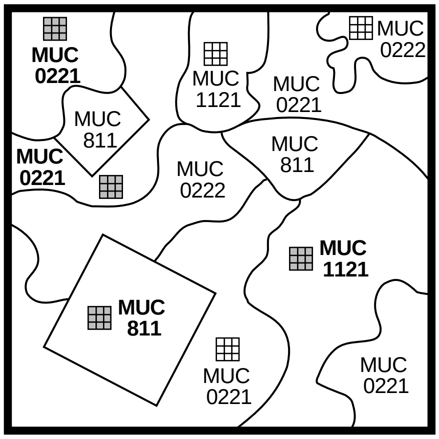


For each area outlined by manual mapping or computer-aided mapping using MultiSpec, assign a MUC class using students' knowledge of the area and data collected from Land Cover Sample Sites.

⊞ Land Cover Sample Sites

Figure LAND-I-5: Diagram of Accuracy Assessment Process (continued)

Step 3: Collect Validation Data

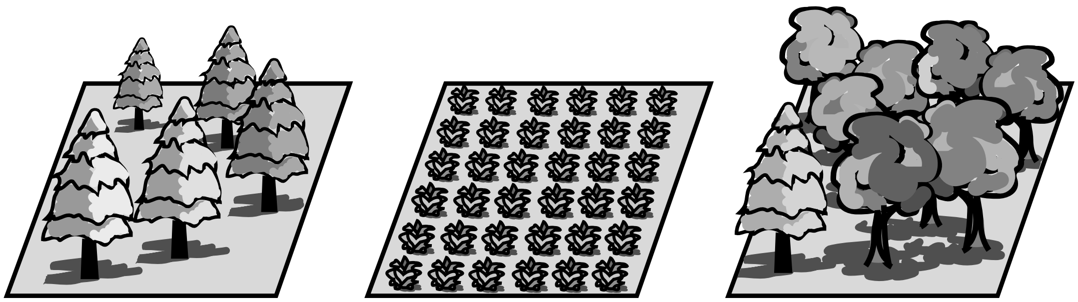


Once the land cover map is made, collect validation data at additional Land Cover Sample Sites to assess the accuracy of the classified map.

Over time, observe and measure as many validation sites as possible for each of the land cover types in your area.

Land Cover Sample Sites

Validation Land Cover Sample Sites



Step 4: Assess Map Accuracy

Validation Data

Student Map Classification

	MUC 0221	MUC 0222	MUC 1121	MUC 811	Row Totals
MUC 0221	|				**1**
MUC 0222	|				**1**
MUC 1121			|		**1**
MUC 811				|	**1**
Column Totals	**2**	**0**	**1**	**1**	**4**

Overall Accuracy = 3/4 x 100 = 75%

Compile the data on the Accuracy Assessment Work Sheet and use the Work Sheet to build a difference/error matrix to compare the Student Map Classification data to the Validation Data from Land Cover Sample Sites.

From the difference/error matrix, calculate accuracy assessment percentages to assess how accurate your land cover type map is.

The Mapping and Accuracy Assessment Process

Figures LAND-I-5 show the logical steps in producing a land cover type map and assessing its accuracy. There are two options for creating a map. The first is to create it by hand from prints of your satellite image following the *Manual Land Cover Mapping Protocol*. The second is to create it electronically from a digital version of the satellite image using the MultiSpec software and following the *Computer-aided Land Cover Mapping Protocol*. You are encouraged to begin collecting data for Land Cover Sample Sites before you begin this mapping process. Student observations of individual sites are valuable even if your students do not complete a land cover map of their own because scientists and students in future years or neighboring schools can use your data in their own land cover type maps.

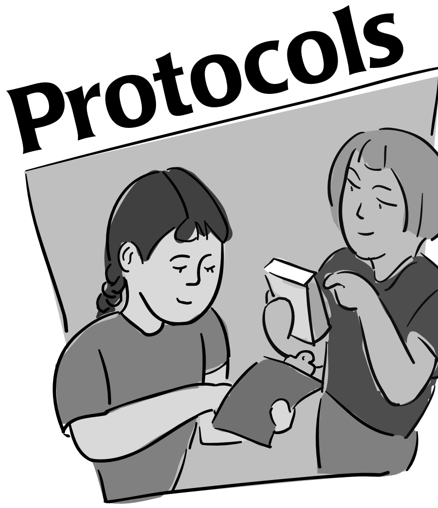
The process is as follows: (1) Collect representative Land Cover Sample Sites of various land cover types. Collect as many of these as you can. Try to collect at least one representative Sample Site for each land cover type that you observe in your Study Site. (2) Create a land cover type map using the MUC System. Use either the *Manual Land Cover Mapping Protocol* and the hard copy prints of the Landsat Thematic Mapper imagery or the *Computer-aided Land Cover Mapping Protocol* with the MultiSpec image processing software and the digital image. Use the sites you collected to assist you in making the map. (3) Collect additional Land Cover Sample Sites. Collect as many of these as you can. (4) Assess the accuracy of your land cover type map by comparing the map you created to the Land Cover Sample Sites collected in your Study Site that students have measured and not used to create their map.

Implementation Considerations

Sequencing, Interconnections, and Interdependence of Learning Activities and Protocols

In order to report data for the main protocol, the *Land Cover Sample Site Protocol*, students must be able to carry out other protocols – the *Biometry Protocol* and the *GPS Protocol*. In addition, students must be able to use MUC to classify land cover, pace accurately, use a compass, and make and know how to use a densiometer and clinometer correctly. It is highly recommended that you use the order below to effectively implement the *Land Cover/Biology Investigation*. Note that *Pre-Protocol Learning Activities* are necessary to ensure that students are familiar with the key concepts and skills required to carry out the protocols.

1	*Getting to Know Your Satellite Imagery* and *GLOBE Study Site Learning Activity*	Investigation Prep, Strongly Recommended
2	*Pacing* and *Compass* (See ***Investigation Instruments***)	Protocol Prep
3	*GPS Protocol* (See *GPS Investigation*)	Imbedded Protocol
4	Make and practice using a *Clinometer* and *Densiometer*, learn how to use and read a *Tape Measure* (See ***Investigation Instruments***)	Protocol Prep
5	*Site-Seeing Learning Activity*	Recommended
6	***Biometry Protocol***	Imbedded Protocol
7	*Leaf Classification Learning Activity*	Pre-Protocol, Strongly Recommended
8	Practice with the *MUC System*	Imbedded Skill
9	With the above skills, students should be able to carry out the ***Land Cover Sample Site Protocol.***	
10	*Odyssey of the Eyes Learning Activity*	Pre-Protocol, Strongly Recommended
11	*Manual Classification: A Tutorial for Beverly, MA Image* OR *Introduction to the MultiSpec Program* and the *Unsupervised Clustering Tutorial* (See *MultiSpec CD*)	Protocol Prep, Strongly Recommended
12	After doing at least one *Land Cover Sample Site Protocol*, students should carry out either the ***Manual Land Cover Mapping*** or ***Computer-aided Land Cover Mapping Protocol.***	
13	Collect many more Land Cover Sample Site data	
14	*Bird Beak Accuracy Assessment Learning Activity*	Pre-Protocol, Strongly Recommended
15	**Carry out an *Accuracy Assessment* on their Land Cover Type Maps**	
16	*Change Detection Tutorial*	Protocol Prep, Strongly Recommended
17	***Change Detection Protocol***	Culmination of Investigation
18	*Discovery Area Learning Activity*	Post-Protocol Learning Activity
19	*Using GLOBE Data to Analyze Land Cover Learning Activity*	Post-Protocol Learning Activity



Sample Site Selection and Set-Up

Students select a 90 m x 90 m homogeneous site to carry out the Land Cover Sample Site Protocol and set-up the site to take the appropriate measurements.

Investigation Instruments

Students learn to use the MUC System, make and learn how to use the densiometer and clinometer. They also use a tape measure and determine their pace. This can be completed as one activity or in separate pieces. Students should also review how to use a compass. Instructions for this can be found in the GPS Investigation.

Land Cover Sample Site Protocol

Students locate, photograph, and determine the MUC class for 90 m x 90 m areas of homogeneous land cover.

Biometry Protocol

Students measure properties of vegetation and identify species in order to classify land cover using the MUC System and to provide supplemental information about their site.

Manual Land Cover Mapping Protocol

Students outline and label different areas of land cover as seen on their Landsat TM image to create a land cover map.

*Computer-aided Land Cover Mapping Protocol**

Students use MultiSpec to perform unsupervised clustering of their Landsat TM image and then assign MUC classes to every cluster to create a land cover map.

*Land Cover Change Detection Protocol**

Using MultiSpec, students compare two images of their GLOBE Study Site; one from the 1990's and one from the 2000's, to determine how the land cover has changed in that time span.

*Fire Fuel Ecology Protocol**

Students take additional measurements of fire fuel at Land Cover Sample Sites.

* See the full e-guide version of the *Teacher's Guide* available on the GLOBE Web site and CD-ROM.

Sample Site Selection and Set-Up

Overview

You will choose multiple Land Cover Sample Sites within your 15 km x 15 km GLOBE Study Site. These sample sites will serve as the locations where you take land cover measurements. You will need these measurements to create your land cover type map. Preferably, you should collect at least one Sample Site for each class of land cover that you observe in your Study Site. You will need data from additional Sample Sites to perform an accuracy assessment to validate the land cover map you created. You may also decide to establish additional Sample Sites whenever you are unsure or curious about the land cover in any area. Some of these sites you may only visit once. In other sites, you may want to study changes in vegetative growth throughout the seasons so you may visit these sites frequently. The following provides instructions on how to select and setup these Sample Sites.

Instructions

ALL Land Cover Sample Sites within the GLOBE Study Site must have the following characteristics:

- Homogeneous – the same MUC class throughout.
- 90 m x 90 m in size.
- Oriented in the cardinal directions
  See *How to Lay-Out Land Cover Sample Site.*

All Land Cover Sample Sites are visited at least once but can be visited multiple times during different times of the year, or different years, in order to conduct studies on changes in biomass over time.

For instance, instead of taking measurements only ONCE during peak growth, measurements can be taken TWICE a year, every year. Your semiannual visit should occur once during peak growing season and once during the least active season (summer vs. winter, rainy season vs. drought, etc.). If you have no temperature or rainfall-dependent seasonality in your region, take measurements only once a year.

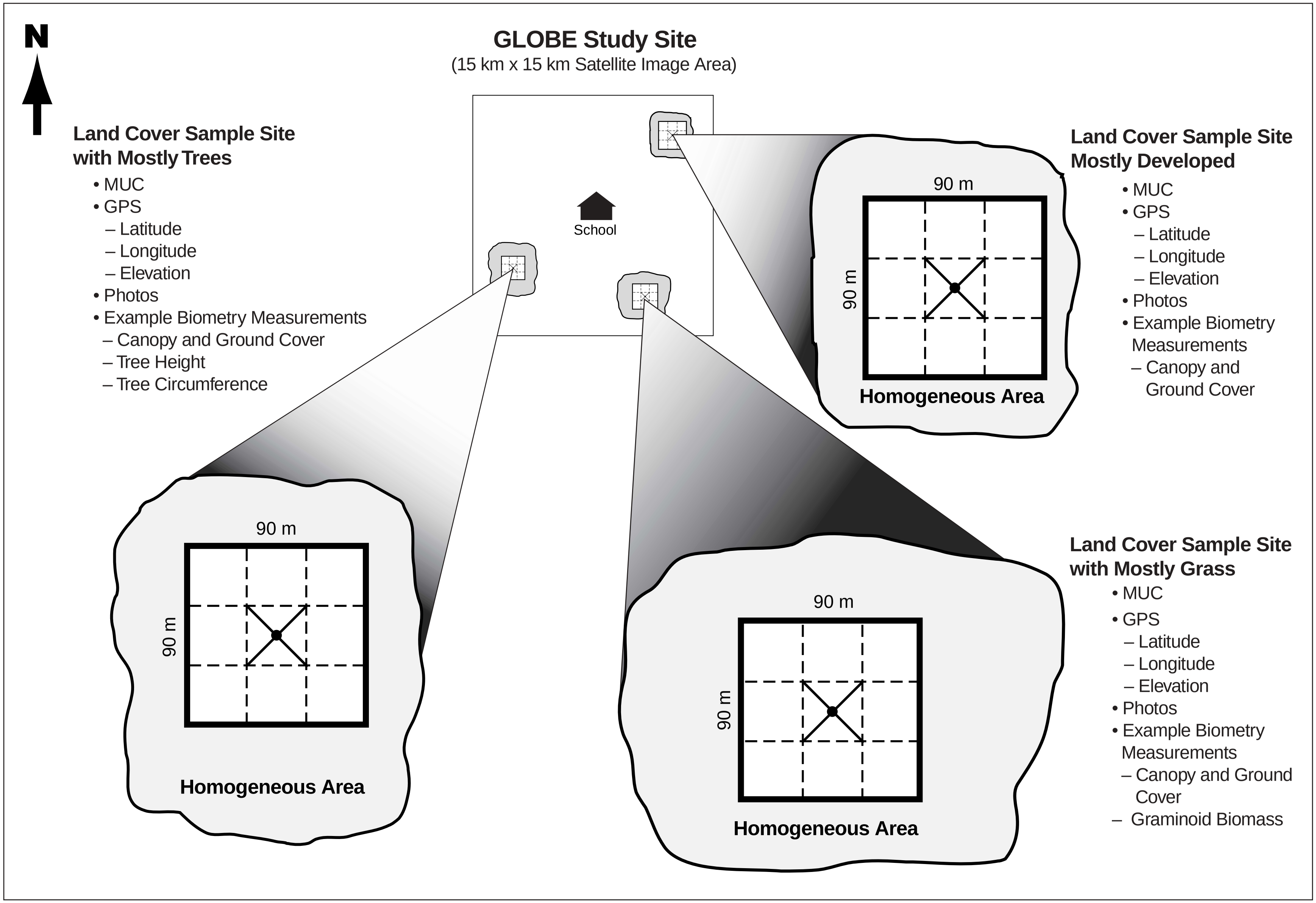
You should permanently mark any trees and shrubs that you measure, since you will return to measure the same ones each time. When you enter your data, make sure that you enter the tree or shrub heights and circumference in the same order each time. This way, you will be describing changes/growth in the same tree or shrub when you report your data.

How to Lay-Out a Land Cover Sample Site

Select a 90 m x 90 m homogeneous area. Use your Landsat TM images and/or your local knowledge to help you locate candidate sites. An area that is homogeneous has the same MUC class throughout the site.

In order to determine if your site is at least 90 m x 90 m in the cardinal directions, pace out

Figure LAND-SS-1: Types of GLOBE Land Cover Sites and Examples of Measurements to Take



(refer to *Pacing* in *Investigation Instruments*) 90 m from one of the corners of the site. Pace in two directions, either North or South AND either East or West. This will give you an estimate of where two more corners are. Estimate the location of the fourth corner. If the entire area is homogeneous, the site is appropriate. (For example, if a 30 m x 30 m area within a forested site has less than 40% canopy cover, the site is not homogeneous.)

Name the site. The Site Name should be unique and identify the site unequivocally. It should not be frivolous.

Note: Areas that look the same on the Landsat image may not be homogeneous and may not have the same MUC class throughout the site. You must make the final determination at the site.

How to Take Biometry Measurements

Once you have established that the site is a 90 m x 90 m homogeneous area aligned in the cardinal directions (N, S, E, and W), you need to determine its MUC Level 1 class. Biometry measurements are taken in the center 30 m x 30 m pixel of the 90 m x 90 m Land Cover Sample Site. Students take some of the biometry measurements as they pace along a diagonal(s) of the center pixel.

The amount and types of biometry measurements are determined by the information you need in order to classify the site to the most detailed level of the MUC System. See Figure LAND-SS-1 for examples of what measurements might be appropriate in specific types of land cover sites. Canopy cover and ground cover should almost always be taken in a natural site. These measurements will help you determine the Level 1 MUC class. Tree and shrub species identification, as well as tree, shrub and/or graminoid height, will help you determine the higher level MUC classes. Tree and shrub circumferences and graminoid biomass are helpful to scientists and to your students when they are studying changes in biomass over time or making specific classifications using satellite imagery. Refer to the *Biometry Protocol* for detailed instructions.

If the site is not visible from the road/path, record the related compass directions and number of paces needed to reach the corner or center of the site from the road/path. You can mark the corners or the center of your site for future visits. While this is not necessary, you may choose to. If there is a chance you may return at a later date, you should mark the center of the 90 m x 90 m site so you can quickly find it.

Take Biometry measurements following the *Biometry Protocol*. This will involve doing the following:

- Mark the center of the 90 m x 90 m site where you will be taking measurements. See Figure LAND-SS-2.
- Divide the students into four groups. Assign each group a direction to walk and take canopy and ground cover measurements along a diagonal from the center. Using a compass, assign each group one of the following directions: NE (45˚), SE (135˚), SW (225˚), and NW (315˚).
- Each diagonal measures 42.4 m, each group should walk half of a diagonal or 21.2 m.
- If you choose, put markers at each corner.
- Combine the data from each group in order to choose your final MUC class, and submit the data to GLOBE.

Figure LAND-SS-2: How to Take Biometery Measurements

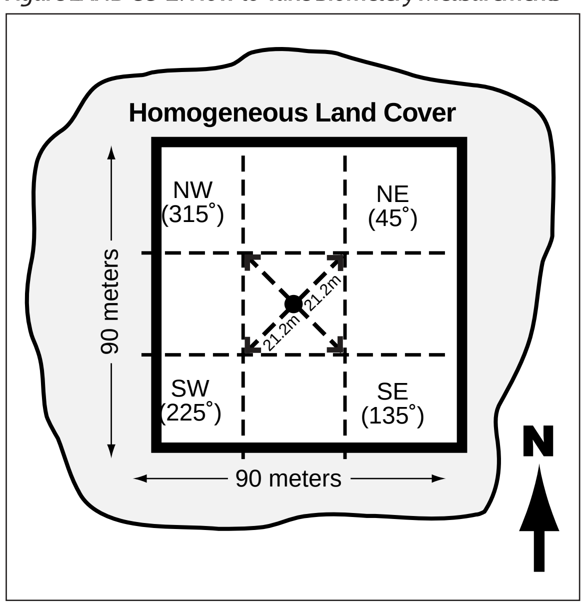
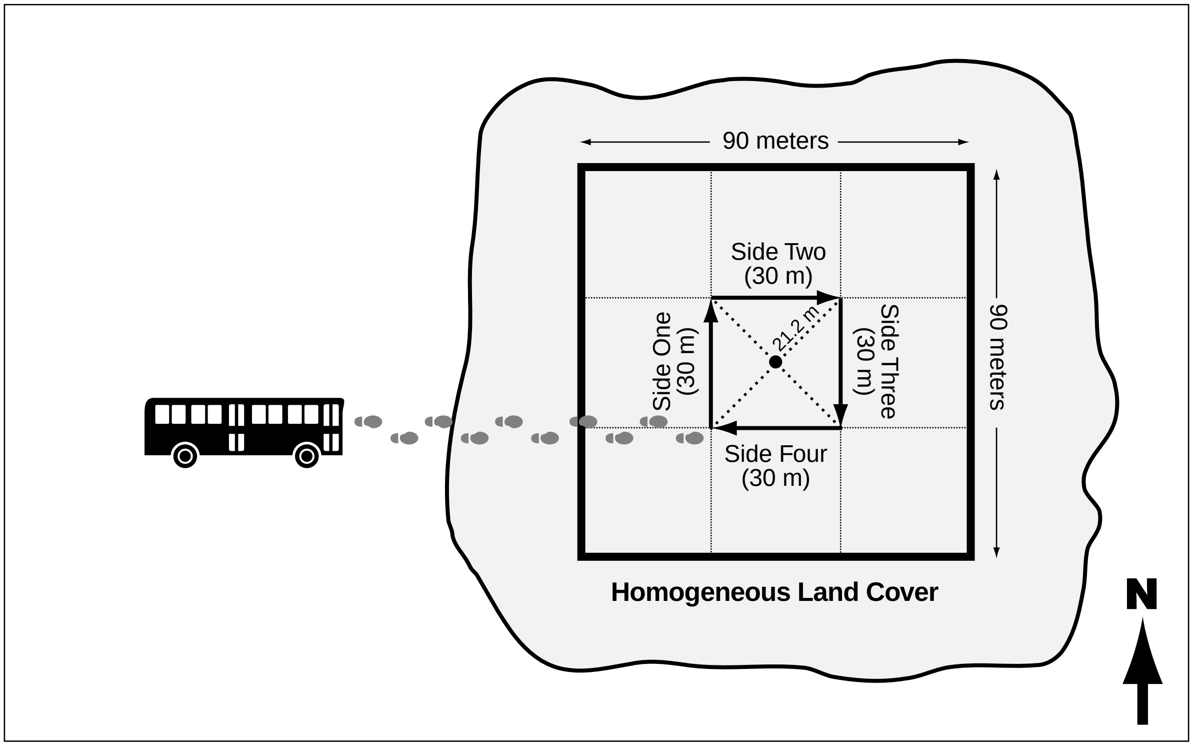


Figure LAND-SS-3: Marking the Center Pixel



If you choose to spend additional time in the field or would like to practice additional pacing and compass skills, here is one way to mark the center pixel of a 90 m x 90 m Land Cover Sample Site. See Figure LAND-SS-3.

- Place a marker where you want one corner of your center pixel to be.
- Use your compass and measuring tape to move 30 meters in a cardinal direction (North, South, East, or West). Place a second marker at the end of this transect. This forms side one.
- From the second marker, move 30 meters perpendicular to side one. Place a third marker at the end of this transect. This forms side two.
- From the third marker, move 30 meters perpendicular to side two and parallel to side one. Place a fourth marker at the end of this transect. This forms side three.
- From the fourth marker, move 30 meters toward your original marker. If this transect ends within 2 to 3 meters of the original marker, you are successful. If you are farther away from the marker, check your compass bearings for each side, check the length of each side, and try again.
- Establish the center of your square by pacing the diagonal transects of the square and placing a marker where the two paths intersect. You may use string to make these diagonals. Also note that the two diagonals should be of equal length.

Frequently Asked Questions

1. What if our homogeneous site is not 90 m x 90 m?

If your site is not homogeneous, you will need to find another site that is at least 90 m x 90 m where the land cover is the same throughout.

2. In the 1997 GLOBE *Teacher's Guide,* the *Land Cover/Biology Investigation* talks about Qualitative and Quantitative Land Cover Sample Sites and Biology Study Sites, but not in this version. Why? How has the chapter changed?

In this 2003 version of the *Teacher's Guide*, we removed the terminology for the different types of Land Cover Sites. In the 1997 version, biometry data were collected and entered in the GLOBE database only for Quantitative Land Cover Sample Sites and Biology Study Sites for Closed Forest, Woodland, and Herbaceous Vegetation (MUC 0, 1, and 4). Now biometry data can be collected for most MUC classes. It is up to teachers and students to decide how much biometry data should be collected. We would like you to collect ground and canopy cover data along the entire length of both diagonals within the 30 m x 30 m center area of your 90 m x 90 m site.

3. What should we do if we have already established a Biology Study Site, a permanent Land Cover site to which we return year after year, but it is not a 90 m x 90 m homogeneous area?

If the area around the Biology Study Site is homogeneous with your old Biology Study Site, you can use it, simply expand the area so it is 90 m x 90 m around your center. This will now be simply called a Land Cover Sample Site. You can still visit it repeatedly and take measurements in it. However, if the area around your old Biology Site is not homogeneous, your data will be difficult to compare with satellite images. There is a certain amount of error in the GPS readings, so even if you are in the center of the site, the reading could actually place you anywhere in the 90 m x 90 m area surrounding the center. You will need to find another suitable site. You could still use the old Biology Study Site for practice.

4. What can I do in an urban area?

You can perform the full investigation. In an urban area, most of the sites will be developed rather than natural classes. This is fine, so collect as many Land Cover Sample Sites as you can. These are very important to scientists because urban land cover types are difficult to identify and distinguish in Landsat TM imagery.

5. What if a pond runs through our 90 m x 90 m area?

If a pond or stream runs through your 90 m x 90 m site, it is not homogeneous and is not a valid site. Try to move the site over to exclude the pond and make it homogeneous.

6. What if a stream runs through our site?

If the stream is so small (narrow) that it doesn't alter the MUC class of any 30 m x 30 m part of the site, it is ok. If not, move the site to exclude the stream.

7 What if the site is on private property?

If the site is on private property, please get permission before entering the area.

8. What do I do if my Land Cover Sample Site has experienced catastrophic change since my last visit?

If your site experiences catastrophic change (i.e. fire, wind damage, hurricane, tornado) between visits, please describe this in the metadata section and do the measurements on any existing vegetation (trees, graminoid vegetation). Scientists are very interested in rates of recovery or succession in such sites. If the 90 m x 90 m site is homogeneous, please do the *Land Cover Sample Site Protocol.*

9. There is a small clearing about 10 m x 10 m in area in our forested site. Is the site still homogeneous?

Yes, if the 30 m x 30 m area that surrounds the clearing has the same MUC class as the rest of the site.

Investigation Instruments

Overview

Before you collect field data, be certain you have all the necessary equipment as listed in the *Field Guides* for the protocols. Some of the instruments used in the *Land Cover/Biology Investigation* you can make yourself and/or require special instruction regarding their use. This section details the construction and use of these instruments, which include:

A. The MUC System – This is the land cover classification system used by GLOBE. To perform a classification according to the MUC system, you will need to have either the *MUC System Table* (given later in this section) and the *MUC Glossary of Terms* (found in the *Appendix* of this chapter) or the *MUC Field Guide* (supplied by GLOBE as a separate book). You will also need to be familiar with the system and its conventions.

B. Densiometer – an instrument used for taking measurements of canopy cover as part of the biometry measurements described in the *Biometry Protocol*. You will need to construct and become familiar with the use of densiometers before taking field measurements.

C. Clinometer – an instrument used for measuring tree height as part of the biometry measurements described in the *Biometry Protocol*. You will need to construct and become familiar with the use of clinometers before taking field measurements.

D. Pacing – a technique used to easily measure distances during the Investigation. It is important that you measure the length of your pace and become comfortable with using this measurement technique.

E. Tape Measure – Used extensively throughout your land cover investigation.

At the end of this section, you will find the *Investigation Instrument Assessment*. Before you proceed to the field, use this assessment to make sure you know how to use the instruments correctly.

A. The MUC System

MUC as a Classification System

The labeling or classification of land cover is one of the major focuses of the *Land Cover/Biology Investigation*. In order for students, teachers and scientists who use GLOBE data to understand exactly what kind of land cover is identified at a site, we must all have a common land cover "language." The GLOBE Program uses the Modified UNESCO Classification (MUC) System, a classification system which follows international standards and uses ecological terminology for the identification of specific land cover classes. The Land Cover Team modified a classification system used by the United Nations Educational, Scientific and Cultural Organization (UNESCO) by adding developed land cover and made some other small changes.

All classification systems, including the MUC System, have four characteristics. These are:

1. All classification systems have labels, which are the titles of the classes, and definitions or rules, the criteria you apply in order to decide the appropriate class an object belongs in.
2. All systems are arranged in a *hierarchical* (multiple levels of classes) or branching structure. At any level of detail, all the different classes should be able to "collapse" into the next, less detailed, level of the system and be consistent with the definition of that class level.
3. They are totally *exhaustive,* that is there is a class for every data point or object.
4. Finally, every system is *mutually exclusive*, meaning there is one and only one appropriate class for every data point or object.

By using a standard international classification system, all the GLOBE data may be compiled into a single regional or global land cover data set. This classification system is a tool for putting every possible land cover type on Earth into a unique land cover class. Thus, ground data may be gathered and used to validate remotely sensed data following the same scientific protocols worldwide. This classification system enables GLOBE participants to accurately describe the land cover at any point on Earth using the identical criteria as all other GLOBE participants. In order to collect information about Land Cover Sample Sites, you must understand how to use the MUC System.

MUC System Organization

There are two components of the MUC System. Part one is the outline of the classification system, the *MUC System Table* (given later in this section), containing the hierarchical list of labels for every class. Part two is the *MUC Glossary of Terms* (found in the *Appendix* of this chapter), with rules and definitions. These two parts are combined in the *MUC Field Guide*. At a GLOBE training, you will receive the *MUC Field Guide* in your teacher's kit. You and your students can choose to use the *MUC System Table* and the *MUC Glossary of Terms* or the *MUC Field Guide* in your classification. Some students choose to use both. However, no matter what you use, before classifying any land cover type, it is crucial to *always* check the definition of the particular land cover class you believe is appropriate. Even if you think you know what a Closed Forest is, you should check the definition to confirm that your site is, in fact, a Closed Forest and not a Woodland.

MUC has a hierarchical, or decision tree structure, with 10 Level 1 classes. These classes are very general and easily identified. You must select one unique MUC class to identify a land cover type at each MUC level, beginning at Level 1. Within each Level 1 class there are two to six more detailed Level 2 classes. Level 2 classes are still quite general and easily distinguished. Levels 3 and 4 are more specific communities or vegetative associations. The hierarchical structure of the MUC System simplifies the classification process. At each level your choices are restricted to only those classes which fall within the single class you have selected at the previous level. Thus while the whole MUC System has over 150 classes, at each step your choice is typically among only three to six land cover types.

In order to conduct the *Land Cover/Biology Investigation,* it is necessary to begin by identifying the MUC Level 1 class for each homogeneous Land Cover Sample Site. Each Level 1 class is general and can be identified by estimating the percentage of the canopy and ground cover by the dominant land cover at the sample site. Often,

Table LAND-SS-1: Level 1 MUC Land Cover Classes

MUC Code	MUC Level 1 Classes	Coverage Required
0	Closed Forest	>40% trees, at least 5 meters tall, crowns interlocking
1	Woodland	>40% trees, at least 5 meters tall, crowns not interlocking
2	Shrubland or Thicket	>40% shrubs or thickets, 0.5 to 5 meters tall
3	Dwarf-Shrubland or Dwarf-Thicket	>40% shrubs or thickets, under 0.5 meters tall
4	Herbaceous Vegetation	>60% herbaceous plants, grasses, and forbs (broad-leaved)
5	Barren	<40% vegetative cover
6	Wetland	>40% vegetative cover, includes marshes, swamps, bogs
7	Open Water	>60% open water
8	Cultivated Land	>60% cultivated species
9	Urban	>40% urban land cover (buildings, paved surfaces)

the percent cover can be visually estimated. Sometimes it will be necessary to take a measurement of the dominant land cover to accurately determine the MUC Level 1 class. The procedure for taking this measurement is found in the *Biometry Protocol*. Table LAND-SS-1 shows the 10 MUC Level 1 classes. Once the MUC Level 1 class is selected, then only those associated MUC Level 2 classes should be considered. The same process is followed for MUC Level 3 and MUC Level 4. It is critical that the definitions of each class be carefully checked to make sure that the correct class is chosen.

Using the MUC System

Using the MUC System Glossary of Terms and Table in the Teacher's Guide

When classifying land cover using the MUC System, always begin with the most general classes (Level 1) and proceed sequentially to the more detailed (higher level) classes. There are 10 Level 1 land cover classes in MUC. Eight of these choices are natural land cover and two are developed land cover.

The MUC System has 10 Level 1 classes, including Closed Forest, Woodland, and Urban. The Level 2 classes within Closed Forest are Mainly Evergreen, Mainly Deciduous, and Extremely Xeromorphic (Dry). These Level 2 classes contain more detail than the Level 1 class, Closed Forest, and they may all be collapsed into the Closed Forest class. In other words, any member of one of these three Level 2 classes is always a member of the Closed Forest Level 1 class. See Table LAND-SS-2. This is a condensed version of MUC, showing only the Level 1 and Level 2 classes.

The MUC System has up to four levels of classes arranged hierarchically. Each higher level is based on more detailed properties of land cover. MUC class "codes" of up to four digits are associated with each MUC class, with one digit for each level in the class. See Table LAND-SS-3.

To Classify Land Cover Using the MUC System Table and the MUC Glossary of Terms

- Observe the land cover site and read the definitions for the 10 Level 1 classes. Pick the one that best describes the site. If necessary, take measurements of vegetation height, canopy cover and ground cover and identify dominant and co-dominant vegetation in order to help you decide which Level 1 class is the best choice. See *Field Guides* for *Biometry Protocol.*
- Once you have chosen the Level 1 class, read the definitions of the Level 2 classes you have to choose from. If none of the definitions seem to fit, go back and rethink your Level 1 choice.
- Choose the Level 2 class that best describes the land cover site. You may need to take biometry measurements and reread the definitions.
- Once you have chosen the Level 2 class, read the definitions of the Level 3 classes you have to choose from. If none of the definitions seem to fit, go back and rethink your Level 2 choice. If there are no Level 3 choices, you are done.
- Choose the Level 3 class that best describes the land cover site. You may need to take biometry measurements and reread the definitions.
- Once you have chosen the Level 3 class, read the definitions of the Level 4 classes you have to choose from. If none of the definitions seem to fit, go back and rethink your Level 3 choice. If there are no Level 4 choices, you are done.
- Record the MUC class (up to 4 digits) in the appropriate place on your *Data Sheet.*

Table LAND-SS-2: MUC Level 1 and 2

	Level 1	Level 2
Natural Cover	0 Closed Forest	01 Mainly Evergreen 02 Mainly Deciduous 03 Extremely Xeromorphic (Dry)
	1 Woodland	11 Mainly Evergreen 12 Mainly Deciduous 13 Extremely Xeromorphic (Dry)
	2 Shrubland or Thicket	21 Mainly Evergreen 22 Mainly Deciduous 23 Extremely Xeromorphic (Subdesert) Shrubland or Thicket
	3 Dwarf-Shrubland or Dwarf-Thicket	31 Mainly Evergreen 32 Mainly Deciduous 33 Extremely Xeromorphic (Subdesert) Dwarf-Shrubland or Dwarf Thicket 34 Tundra
	4 Herbaceous Vegetation	41 Tall Graminoid 42 Medium Tall Graminoid 43 Short Graminoid 44 Forb Vegetation
	5 Barren Land	51 Dry Salt Flats 52 Sandy Areas 53 Bare Rock 54 Perennial Snowfields 55 Glaciers 56 Other
	6 Wetland	61 Riverine 62 Palustrine 63 Estaurine 64 Lacustrine
	7 Open Water	71 Freshwater 72 Marine
Developed Cover	8 Cultivated Land	81 Agriculture 82 Non-agriculture
	9 Urban	91 Residential 92 Commercial and Industrial 93 Transportation 94 Other

How to Use the MUC Field Guide

The *MUC Field Guide* is designed to lead you through the MUC levels from the most general (Level 1) to the most detailed. The most detailed will be Level 2, 3, or 4, depending on the particular land cover class. At each level, either you will be asked one or more questions about the site or given a list of options from which you select the best description of your site. Your selection or response to a question (usually either YES or NO) will direct you to the next question until you finally reach the most specific MUC level for your site. When you reach the most detailed level, you will be told 'DONE'.

Every class within each level has a unique identifier or numerical code. Your most detailed classification will be identified by a string of these numbers. In the *MUC Field Guide*, the definition from the *MUC Glossary of Terms* is given for each MUC level. The questions described above and these definitions are given on the left side of the page. Along the right side of the page, there may be definitions of words used in defining the MUC class, as well as some notes to help you decide how to make a selection. Drawings are interspersed throughout the guide to help you better understand the types of vegetation and the rules used in the MUC System. A table showing all the MUC classes is included at the end of this guide.

Helpful Hints

- Your students should refer to the definitions in the *MUC Field Guide* or *MUC Glossary of Terms* when determining MUC for an area.
- Distinguishing among some MUC classes requires quantitative measurements of the percentage of your site that is covered by different types of vegetation and/or the height of the dominant vegetation. You can identify the appropriate MUC class using the measurements found in the *Biometry Protocol.*
- To classify land cover, you may use either the *MUC Field Guide,* or the *MUC Glossary of Terms* along with the *MUC System Table*.
- In order to simplify the *MUC System Table* and *MUC Glossary of Terms* for students, some teachers have modified them by eliminating some of the highly unlikely choices, i.e. glaciers and salt water in a land-locked desert community, xeromorphic (extremely dry) forests in a very humid environment, etc.

Table LAND-SS-3: MUC System Table

	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	NOTES AND EXAMPLES
Natural Cover	0 Closed Forest	01 Mainly Evergreen	011 Tropical Wet (Rain)	0111 Lowland	
				0112 Submontane	Costa Rica: Atlantic slope
				0113 Montane	Costa Rica: Sierra de Talamanca
				0114 Subalpine	
				0115 Cloud	Jamaica: Blue Mountains
			012 Tropical and Subtropical Seasonal	0121 Lowland	
				0122 Submontane	
				0123 Montane	
				0124 Subalpine	
			013 Tropical and Subtropical Semi-Deciduous	0131 Lowland	*Ceiba* spp.
				0133 Montane and Cloud	
			014 Subtropical Wet	0141 Lowland	Queensland, Australia, and Taiwan
				0142 Submontane	
				0143 Montane	
				0144 Subalpine	
				0145 Cloud	
			015 Temperate or Subpolar Wet	0151 Temperate	Chilean Coast
				0152 Subpolar	
			016 Temperate with Broad-Leaved Deciduous	0161 Lowland	
				0162 Submontane	
				0163 Montane	
				0164 Subalpine	
			017 Winter-Rain Broad-Leaved Sclerophyllous	0171 Lowland and Submontane >50m	*Eucalyptus regnans, E. diversicolor*
				0172 Lowland and Submontane <50m	USA: California live-oak forest
			018 Tropical and Subtropical Needle-Leaved	0181 Lowland and Submontane	*Pinus* spp. forest of Honduras and Nicaragua
				0182 Montane and Subalpine	*Pinus* spp. forest of Phillippines and southern Mexico
			019 Temperate and Subpolar Needle-Leaved	0191 Giant (>50 m)	*Sequoia* and *Pseudotsuga* spp., Pacific W. of N. America
				0192 Irregularly Rounded Crowns	*Pinus* spp.
				0193 Conical Crowns	*Picea* and *Abies* spp.; USA California Red Fir forests
				0194 Cylindrical Crowns	Boreal, short branches

Table LAND-SS-3: MUC System Table (continued)

	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	NOTES AND EXAMPLES
Natural Cover	0 Closed Forest	02 Mainly Deciduous	021 Tropical and Subtropical Drought-Deciduous	0211 Broad-Leaved Lowland and Submontane	Northwest Costa Rica
				0212 Montane and Cloud	Northern Peru
			022 Cold-Deciduous with Evergreens	0221 With Evergreen Broad-Leaved Trees and Climbers	Western Europe: *Ilex aquifolium*, *Hedera helix* North America: *Magnolia* spp.
				0222 With Evergreen Needle-Leaved Trees	Northeastern US: maple-hemlock forest
			023 Cold-Deciduous without Evergreen Trees	0231 Temperate Lowland and Submontane Broad-Leaved	
				0232 Montane and Boreal	
				0233 Subalpine and Subpolar	Grades into woodland
		03 Extremely Xeromorphic (Dry)	031 Sclerophyllous-Dominated		
			032 Thorn-Dominated	0321 Mixed Deciduous-Evergreen	
				0322 Purely Deciduous	
			033 Mainly Succulent		
	1 Woodland	11 Mainly Evergreen	111 Broad-Leaved		
			112 Needle-Leaved	1121 Irregularly Rounded Crowns	*Pinus* spp.
				1122 Conical Crowns	Mostly subalpine
				1123 Cylindrical Crowns	Boreal regions: *Picea* spp.
		12 Mainly Deciduous	121 Drought-Deciduous	1211 Broad-Leaved Lowland and Submontane	
				1212 Montane and Cloud	
			122 Cold-Deciduous with Evergreens	1221 With Evergreen Broad-Leaved Trees and Climbers	
				1222 With Evergreen Needle-Leaved Trees	
			123 Cold-Deciduous without Evergreen Trees	1231 Broad-Leaved	
				1232 Needle-Leaved	
				1233 Mixed	
		13 Extremely Xeromorphic (Dry)	131 Sclerophyllous-Dominated		
			132 Thorn-Dominated	1321 Mixed Deciduous-Evergreen	
				1322 Purely Deciduous	
			133 Mainly Succulent		

Table LAND-SS-3: MUC System Table (continued)

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	NOTES AND EXAMPLES
Natural Cover				
2 Shrubland or Thicket	21 Mainly Evergreen	211 Broad-Leaved	2111 Low Bamboo	
			2112 Tuft-Tree	Mediterranean dwarf-palm, Hawaiian tree-fern
			2113 Broad-Leaved Hemi-Sclerophyllous	Subalpine *Rhododendron* thickets, or *Hibiscus tiliaceus* matted thickets of Hawaii, USA
			2114 Broad-Leaved Sclerophyllous	Chapparral or macchia
			2115 Suffruticose	*Cistus* heath
		212 Needle-Leaved or Microphyllous	2121 Needle-Leaved	*Pinus mughus* , "Krummholz"
			2122 Microphyllous	Tropical subalpine
	22 Mainly Deciduous	221 Drought-Deciduous with Evergreen Woody Plants		
		222 Drought-Deciduous without Evergreen Woody Plants		
		223 Cold-Deciduous	2231 Temperate	
			2232 Subalpine and Subpolar	
	23 Extremely Xeromorphic (Subdesert) Shrubland	231 Mainly Evergreen	2311 Purely Evergreen	
			2312 Semi-Deciduous	Australia, N. America: *Atriplex-Kochia-saltbush*
		232 Mainly Deciduous	2321 Without Succulents	
			2322 With Succulents	
3 Dwarf-Shrubland or Dwarf-Thicket	31 Mainly Evergreen	311 Dwarf-Thicket	3111 Caespitose	*Calluna* heath
			3112 Creeping	*Loiseleuria* heath
		312 Dwarf-Shrubland	3121 Cushion	E. Mediterranean: *Astragalus* and *Acantholimon* spp.
		313 Mixed Evergreen and Herbaceous Dwarf-Shrubland	3131 True Evergreen & Herbaceous Mixed	*Nardus-Calluna* heath
			3132 Partial Evergreen & Herbaceous Mixed	Greece: *Phrygana* spp.
	32 Mainly Deciduous	321 Facultative Drought-Deciduous		
		322 Obligate Drought-Deciduous	3221 Caespitose Dwarf-Thicket	
			3222 Creeping Dwarf-Thicket	
			3223 Cushion Dwarf-Shrubland	
			3224 Mixed Dwarf-Shrubland	
		323 Cold-Deciduous	3231 Caespitose Dwarf-Thicket	
			3232 Creeping Dwarf-Thicket	
			3233 Cushion Dwarf-Shrubland	
			3234 Mixed Dwarf-Shrubland	

Table LAND-SS-3: MUC System Table (continued)

	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	NOTES AND EXAMPLES
Natural Cover	3 Dwarf-Shrubland or Dwarf-Thicket	33 Extremely Xeromorphic (Subdesert) Dwarf-Shrubland	331 Mainly Evergreen	3311 Purely Evergreen	
				3312 Semi-Deciduous	
			332 Mainly Deciduous	3321 Without Succulents	
				3322 With Succulents	
		34 Tundra	341 Mainly Bryophyte	3411 Caespitose	
				3412 Creeping	
			342 Mainly Lichen		
	4 Herbaceous Vegetation	41 Tall Graminoid	411 With Trees Covering 10-40 %	4110 Trees: Needle-Leaved Evergreen	
				4111 Trees: Broad-Leaved Evergreen	
				4112 Trees: Broad-Leaved Semi-Evergreen	
				4113 Trees: Broad-Leaved Deciduous	
			412 With Trees Covering < 10 %	4120 Trees: Needle-Leaved Evergreen	
				4121 Trees: Broad-Leaved Evergreen	
				4122 Trees: Broad-Leaved Semi-Evergreen	
				4123 Trees: Broad-Leaved Deciduous	
				4124 Tropical and Subtropical with Trees and Shrubs in Tufts on Termite Nests	Termite savannah
			413 With Shrubs	4130 Shrubs: Needle-Leaved Evergreen	
				4131 Shrubs: Broad-Leaved Evergreen	
				4132 Shrubs: Broad-Leaved Semi-Evergreen	
				4133 Shrubs: Broad-Leaved Deciduous	
				4134 Tropical and Subtropical with Trees and Shrubs in Tufts on Termite Nests	Termite savannah
			414 With Tuft Plants	4141 Tropical with Palms	Bolivia: *Arocomia totai* and *Attalea princeps*
			415 Without Woody Synusia	4151 Tropical	Low-latitude Africa, lower Amazon, upper Nile
		42 Medium Tall Graminoid	421 With Trees Covering 10-40 %	4210 Trees: Needle-Leaved Evergreen	
				4211 Trees: Broad-Leaved Evergreen	
				4212 Trees: Broad-Leaved Semi-Evergreen	
				4213 Trees: Broad-Leaved Deciduous	
			422 With Trees Covering < 10 %	4220 Trees: Needle-Leaved Evergreen	
				4221 Trees: Broad-Leaved Evergreen	
				4222 Trees: Broad-Leaved Semi-Evergreen	
				4223 Trees: Broad-Leaved Deciduous	
				4224 Tropical and Subtropical with Trees and Shrubs in Tufts on Termite Nests	Termite savannah

Table LAND-SS-3: MUC System Table (continued)

	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	NOTES AND EXAMPLES
Natural Cover	4 Herbaceous Vegetation	42 Medium Tall Graminoid	423 With Shrubs	4230 Shrubs: Needle-Leaved Evergreen	
				4231 Shrubs: Broad-Leaved Evergreen	
				4232 Shrubs: Broad-Leaved Semi-Evergreen	
				4233 Shrubs: Broad-Leaved Deciduous	
				4234 Tropical and Subtropical with Trees and Shrubs in Tufts on Termite Nests	Termite savannah
				4235 Woody Synusia of Deciduous Thorny Shrubs	
			424 Open Synusia of Tuft Plants	4241 Subtropical with Open Palm Groves	
			425 Without Woody Synusia	4251 Mainly Sod Grasses	USA, Eastern Kansas: tall-grass prairie
				4252 Mainly Bunch Grasses	New Zealand: *Festuca novae-zelandiae*
		43 Short Graminoid	431 With Trees Covering 10-40 %	4310 Trees: Needle-Leaved Evergreen	
				4311 Trees: Broad-Leaved Evergreen	
				4312 Trees: Broad-Leaved Semi-Evergreen	
				4313 Trees: Broad-Leaved Deciduous	
			432 With Trees Covering < 10 %	4320 Trees: Needle-Leaved Evergreen	
				4321 Trees: Broad-Leaved Evergreen	
				4322 Trees: Broad-Leaved Semi-Evergreen	
				4323 Trees: Broad-Leaved Deciduous	
				4324 Tropical and Subtropical with Trees and Shrubs in Tufts on Termite Nests	Termite savannah
			433 With Shrubs	4330 Shrubs: Needle-Leaved Evergreen	
				4331 Shrubs: Broad-Leaved Evergreen	
				4332 Shrubs: Broad-Leaved Semi-Evergreen	
				4333 Shrubs: Broad-Leaved Deciduous	
				4334 Tropical and Subtropical with Trees and Shrubs in Tufts on Termite Nests	Termite savannah
				4335 Woody Synusia of Deciduous Thorny Shrubs	
			434 Open Synusia of Tuft Plants	4341 Subtropical with Open Palm Groves	
			435 Mainly Bunch Grasses with Woody Synusia	4351 Tropical Alpine with Tuft Plants	
				4352 Tropical Alpine without Tuft Plants	
				4353 Tropical and Subtropical Alpine with Open Stands of Evergreens	
				4354 With Dwarf Shrubs	
			436 Without Woody Synusia	4361 Short-Grass Communities	USA, Colorado: short-grass prairie
				4362 Bunch-Grass Communities	

Table LAND-SS-3: MUC System Table (continued)

	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	NOTES AND EXAMPLES
Natural Cover			437 Short to Medium Tall Mesophytic Communities	4371 Sodgrass Communities	N. America, Eurasia: Low altitude, cool, humid
				4372 Alpine and Subalpine Meadows	High latitudes
	4 Herbaceous Vegetation	44 Forb Vegetation	441 Tall Communities	4411 Fern Thickets	
				4412 Mainly Annual	
				4413 Mainly Perennial Flowering Forbs and Ferns	
			442 Low Communities	4421 Mainly Perennial Flowering Forbs and Ferns	
				4422 Mainly Annual	
	5 Barren Land	51 Dry Salt Flats			
		52 Sandy Areas			
		53 Bare Rock			
		54 Perennial Snowfields			
		55 Glaciers			
		56 Other			
	6 Wetland	61 Riverine			
		62 Palustrine			
		63 Estuarine			
		64 Lacustrine			
	7 Open Water	71 Freshwater			
		72 Marine			
Developed Cover	8 Cultivated Land	81 Agriculture	811 Row Crop and Pasture		
			812 Orchard and Horticulture		
			813 Confined Livestock feeding		
			814 Other Agriculture		
		82 Non-Agriculture	821 Parks and Athletic fields		
			822 Golf Courses		
			823 Cemeteries		
			824 Other Non-Agriculture		
	9 Urban	91 Residential			
		92 Commercial and Industrial			
		93 Transportation			
		94 Other			

Example of MUC Classification

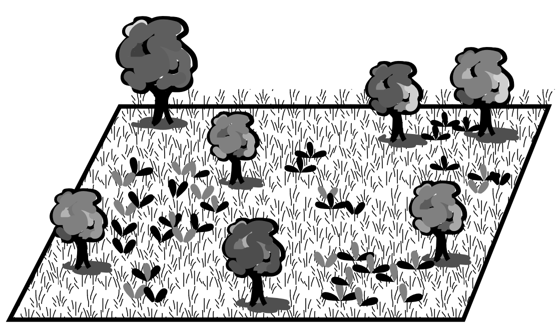
Below is an example for assigning a MUC class to a given homogeneous area. Three additional examples are also in the *Appendix*. This first example is for your students to follow along, while the rest (in the *Appendix*) are for them to try for themselves. Students should be able to confidently assign a MUC class by the time they complete the last example.

The answer for the example below is 4213.

The definitions of the MUC classes and scientific terminology are given in the *MUC Glossary of Terms* and in the *MUC Field Guide.* ALWAYS refer to these definitions rather than trusting your memory or general knowledge when determining the MUC class for an area.

Example 1

For your land cover site (90 m x 90 m), you picked a homogeneous area. This means that the entire area will have the same MUC class. About 80% of the site is covered by graminoid (grass) and forb (broad-leaved) vegetation about 1 meter tall. It is 75% graminoid and 25% forb mix. Broad-leaved deciduous trees cover about 15-20% of the site.



Level 1: Look in the *MUC System Table* at all the Level 1 classes. Note that class 4, Herbaceous Vegetation, is probably the appropriate Level 1 class. Look in the *MUC Glossary of Terms*. Class 4 requires greater than 60% total ground cover of herbaceous vegetation over the entire site. Class 4 is the correct choice.

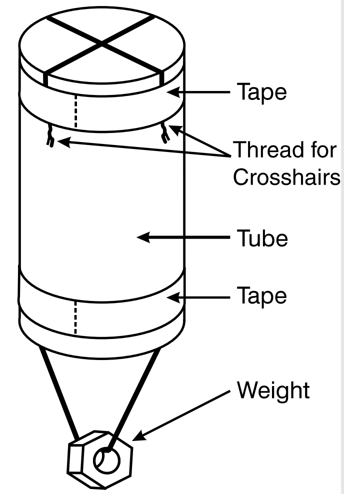
Level 2: Look in the *MUC System Table* at the four choices at Level 2 (41-44). Review the definitions of these four classes in the *MUC Glossary of Terms*. You should determine that, since the dominant cover type (herbaceous) is more than 50% graminoid, the Level 2 land cover type must be Graminoid. Since the graminoid is between 50 cm and 2 m tall, you should select class 42, Medium Tall Graminoid.

Level 3: Look in the *MUC System Table* at the five Level 3 choices (421-425). Since trees cover 15-20% of the site, you should select Class 421, “With Trees Covering 10-40%.” To be sure this is the correct answer, read the definition in the *MUC Glossary of Terms*.

Level 4: You now have four choices at Level 4 (4210-4213). Since the trees are broad-leaved deciduous, you should select class 4213. You have completed your MUC Level 4 classification.

B. Densiometer

Figure LAND-SS-4: Homemade Densiometer



A densiometer is an instrument used for taking measurements of canopy cover as part of the biometry measurements described in the *Biometry Protocol.* The following includes directions to construct and use the densiometer.

Required Materials

- 4 cm diameter by 7.5 cm long tube (toilet paper tubes, construction paper, PCV pipe)
- 34 cm of thread or dental floss
- metal nut or washer
- tape

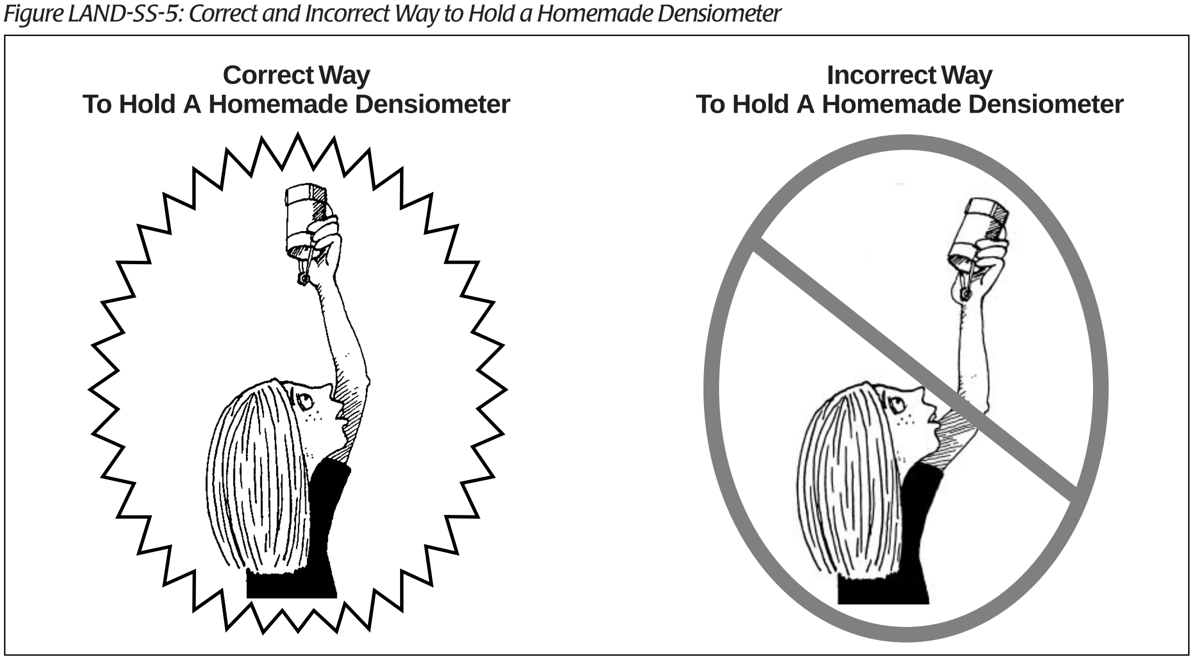
Construction

1. Gather the required materials for each densiometer.
2. Attach (with tape) two threads at right angles across the diameter of one end of the tube to form a crosshair. Leave a slight end hanging at the bottom of the tape so you can tighten the threads if they loosen.
3. Attach (with tape) an 18 cm piece of thread with a metal nut or washer hanging loosely from it across the diameter of the other end of the tube (opposite the crosshairs).

Directions for Use

1. Look up through the densiometer, making sure the densiometer is vertical and the metal nut/washer is directly below the intersection of the crosshairs at the top of the tube. See Figure LAND-SS-5 and Figure LAND-SS-6. **Note:** Only use the densiometer for looking UP at the canopy cover. Do not use it for looking DOWN at ground cover.
2. If you see vegetation, twigs, or branches **touching the crosshair intersection**, you would call this "T" meaning that there is tree canopy or "SB" meaning that there is shrub canopy.
3. If you **do not** see vegetation, twigs, or branches **touch the crosshair intersection**, you would call this minus "–" meaning that you saw the sky above the intersection of the crosshairs.

Figure LAND-SS-5: Correct and Incorrect Way to Hold a Homemade Densiometer



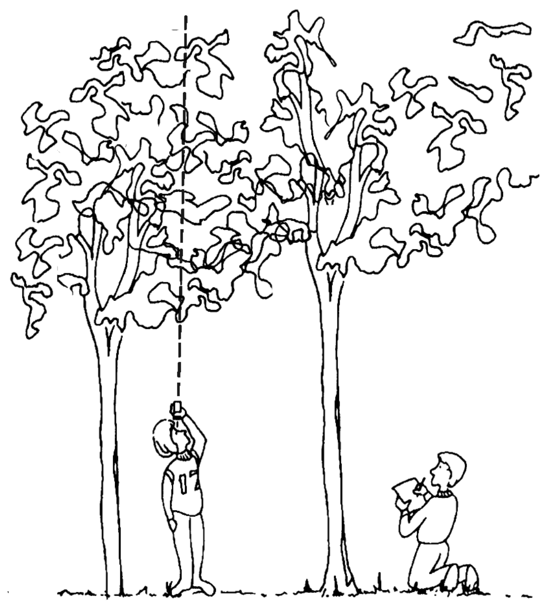
Modified from TEREZA, Association for Environmental Education, Czech Republic (1996).

Frequently Asked Questions

1. What should we do if there is a multi-storied canopy?

If there is a multi-story canopy, try to identify the highest level of the canopy without changing your position. If the vegetation touches the intersection of the crosshairs, mark a "T" or an "SB". See LAND-SS-6.

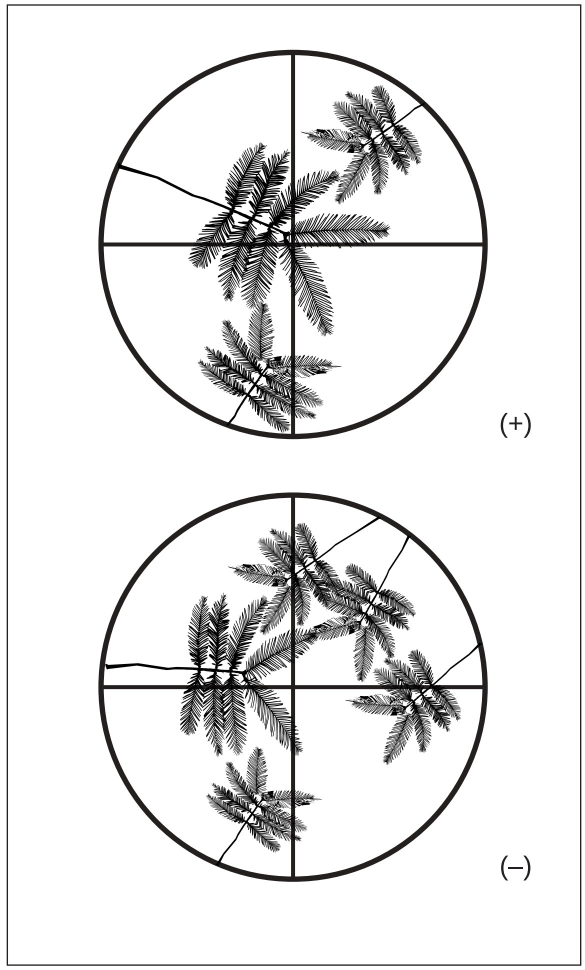
Figure LAND-SS-6: Using a Homemade Densiometer in Multi-Story Canopy



2. What if the entire circle I see through the densiometer is full of vegetation, but there is no vegetation at the crosshairs?

This is a sampling question. The Land Cover/ Biology Team has chosen the intersection of the crosshairs as the sample. Therefore, this would be a (–).

Figure LAND-SS-7: Densiometer Sampling



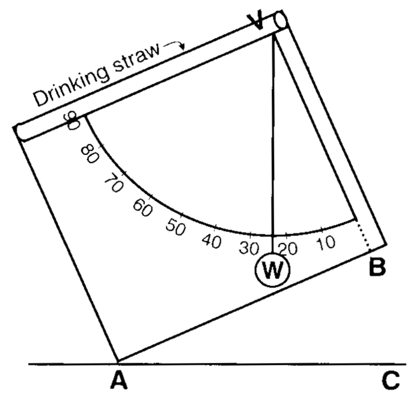
3. What if we can't get to our site during peak vegetation (full leaf-on) conditions?

If you cannot get to your site during peak growth (leaf-on), measure your site during the leaf-off period and try your best to get the peak growth (leaf-on) data, when you can.

C. Clinometer

A clinometer is an instrument used for measuring angles. In GLOBE, you use it to find the angle for calculating tree heights. It is also used to determine obstacles at an Atmosphere Study Site. The calculations work by applying the principles based on the properties of right triangles. You construct and use the clinometer by following the directions and using the formula below. The clinometer also lends itself for additional hands-on teaching exercises of trigonometric principles.

Figure LAND-SS-8: Homemade Clinometer



Modified from Bennett, A. and Nelson, L. (1961) Mathematics an Activity Approach, Allyn & Bacon, Boston

Required Material

- *Clinometer Sheet* and *Table of Tangents* (located in the *Appendix*)
- Piece of stiff cardboard at least the size of the sheets above
- Drinking straw
- Metal nut or washer
- 15 cm of thread or dental floss
- Glue
- Scissors
- Something to punch one small hole
- Tape

Construction

1. Gather the materials for each clinometer.
2. Glue a copy of the *Clinometer Sheet* onto a same-size piece of stiff cardboard (cut cardboard if necessary).
3. Glue a copy of the *Table of Tangents* to the other side of the cardboard.
4. Punch a hole through the marked circle on the *Clinometer Sheet.*
5. Thread one end of a 15 cm piece of thread through the hole and tie or tape it on the *Table of Tangents* side of the cardboard.
6. Tie a metal nut or washer to the other end of the thread so that it hangs in front of the *Clinometer Sheet.*
7. Tape a drinking straw along the designated line on the *Clinometer Sheet,* to use as a sighting device.

   Note: A clinometer measures angles to determine the heights of objects without directly measuring them. It is a simplified version of the quadrant (a medieval measuring instrument), and the sextant (an instrument used to locate the positions of ships). Like these instruments, the clinometer has an arc with graduated degree markings that go from 0 to 90 degrees.

Directions for Use

1. Stand up straight and measure the height of your eyes from the ground. Record this number for future reference.
2. Stand at the same elevation (level ground) as the base of the object that you are measuring.
3. Sight the top of the object through the clinometer's drinking straw. Have your partner read the number of degrees of angle BVW (see Figure LAND-SS-8) by noting where the thread touches the arc on the *Clinometer Sheet*. (Angle BVW is equal to angle BAC, which is the angle of elevation of the clinometer.)
4. Measure the horizontal distance from you to the object that is being measured.
5. If you know the angle of elevation, your eye height, and your distance away from an object, as in Figure LAND-SS-9, you can calculate the height of that object using a simple equation. Add your eye height to the number you determine using the equation below.

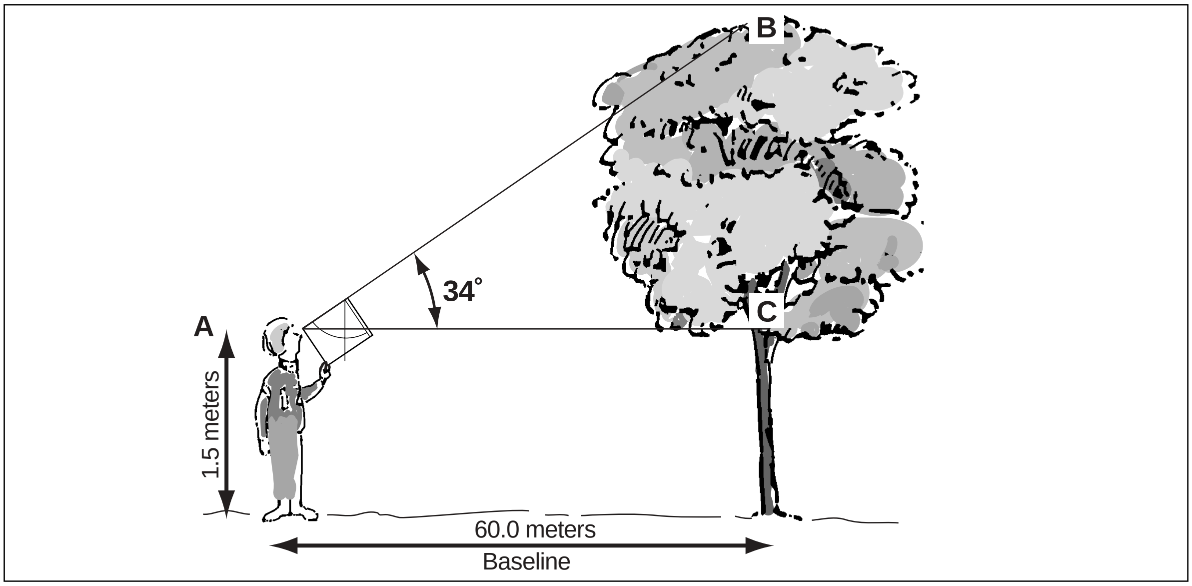
$$BC = AC \times \tan \angle A$$

Height of the Tree above your eye height (BC) = Distance to the Base of the Tree (AC) x Tan of the Angle of the Clinometer (Tan ∠ A)

(see example next page)

Note: If you would like to practice measuring heights before going to your site, find a tall outdoor object for which you know or can directly measure the height (such as a flagpole or the school building). After completing the above process, compare your results with the known height of the object.

Figure LAND-SS-9: Determining the Height of a Tree Using a Homemade Clinometer



Example:

In the example (Figure LAND-SS-9 and LAND-SS-10), a student stands 60 m away from the base of a tree and sites the top of the tree through his clinometer. His eye is 1.5 meters above the ground. He reads an angle of 34 degrees on his clinometer (figures are not drawn to scale). Use your *Table of Tangents* and the following equation to solve for the height of the tree:

TAN 34 = BC/60.0 Therefore,

BC = 60.0 m (TAN 34). Therefore,

BC = 60.0 m (.67) = 40.2 m

Add the height of BC to the height of the clinometer from the ground (your eye level) to get the total height of the tree. In the above example, the height of the tree is 40.2 m + 1.5 m = 41.7 m.

Note: Adjust your distance from the tree so that you are at least as far away from the tree as the tree is tall. For the most accurate measurement, adjust your distance so that the angle of the clinometer is as close to 30 degrees as possible.

Figure LAND-SS-10: Trigometric Equation

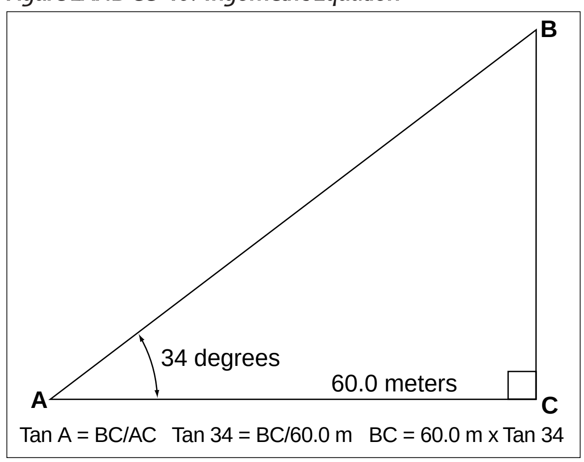
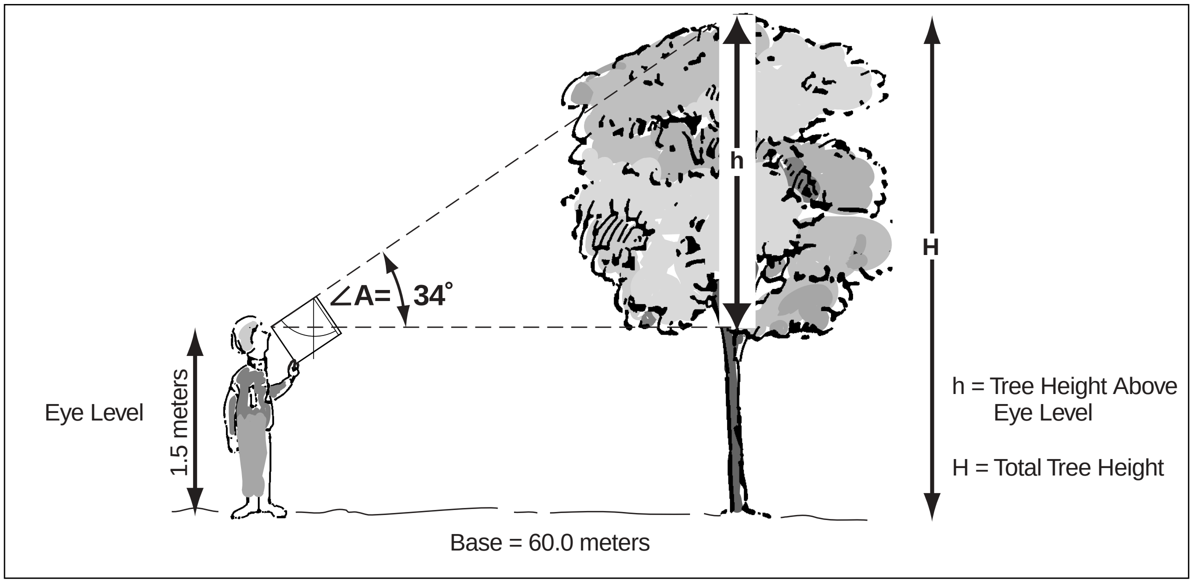


Figure LAND-SS-11: Trigonometric Equation Simplified



For students who are not familiar with geometry yet, here is another way to simplify this example. See Figure LAND-SS-11.

h = Base x Tan ∠ A

h= 60.0m x Tan 34

h = 60.0m x 0.67 = 40.2m

H = h + Eye Level

H = 40.2 + 1.5m = 41.7m

Frequently Asked Questions

1. What if my students are too young to understand the math used to determine tree height?

For younger students, if the angle BVW is 45 degrees, the distance from the tree will equal the height of the tree above the student's eye level. This can be illustrated for students by drawing an isosceles right triangle without any additional explanation of the mathematics involved. Run a tape measure from the student's eye to his or her feet and then to the base of the tree. This distance will equal the height of the tree. See the *Alternate Technique to Measure Tree Height on Level Ground: Simplified Clinometer Technique Field Guide* in the *Biometry Protocol*.

2. What if the tree is leaning?

If the tree is leaning, just measure to the top of the tree as usual.

3. If I cannot be on the same level as the base of the tree I am measuring, how do I estimate the height of the tree? Or what if there is no level ground to measure the tree heights?

There are three methods to handle this problem. They are presented in the *Biometry Protocol's Alternate Techniques to Measure Tree Height Field Guides*. Use the one that seems the most appropriate.

D. Pacing

A pace is equal to walking two steps. Knowing how long your pace is will be helpful throughout your investigation of land cover. Specifically, when you walk diagonals to take measurements at Sample Sites (according to the *Biometry Protocol*), you will need to know how many paces it takes to travel 21.2 meters (the length of half of a diagonal). There are two options given below for determining this number.

Directions for Determining Pace

1. Lay out a 30 meter or longer measuring tape on a flat, open area (a parking lot, field, or hallway is good).
2. Remember that one pace is two steps. Starting with your toe at the 0-meter mark, pace off 10 paces, using a normal stride. It is important to use a normal, comfortable stride because of the wide variety of conditions encountered in the field.
3. Note the marking on the tape where your toe is on the tenth pace. This value is the length of ten of your paces.
4. Divide that value by 10 to find the length of your pace.
5. Repeat Steps 2-4 three times. Calculate the average (by adding up the three lengths of one pace, from Step 4, and dividing by three) to determine your average pace distance.

Example:

Repetition Number	Distance of 10 Paces	Distance of Single Pace
1	17.0 m	1.70 m
2	17.5 m	1.75 m
3	16.8 m	1.68 m
Average Pace = 1.71 meters per pace		

Note: Pacing in the woods or over hilly terrain is quite different than pacing a flat distance in a schoolyard or parking area. Remember the following tips:

- When initially measuring your pace, walk using a comfortable stride. Resist the temptation to take exaggerated steps because your pace will naturally become shorter in the woods or over hilly terrain.
- When pacing up or down a hill, you are actually traveling a shorter horizontal distance than it seems, and you may also pace irregularly due to the terrain. Be aware of your paces and compensate by taking slightly shorter or longer steps as necessary.
- When large objects (boulders, large trees, etc.) are in the way, take a few lateral side steps, pace forward, then take the same number of lateral side steps back to your original compass bearing. See Figure LAND-SS-12. If an observation is required

Figure LAND-SS-12: How to Side Step Around Large Obstacles

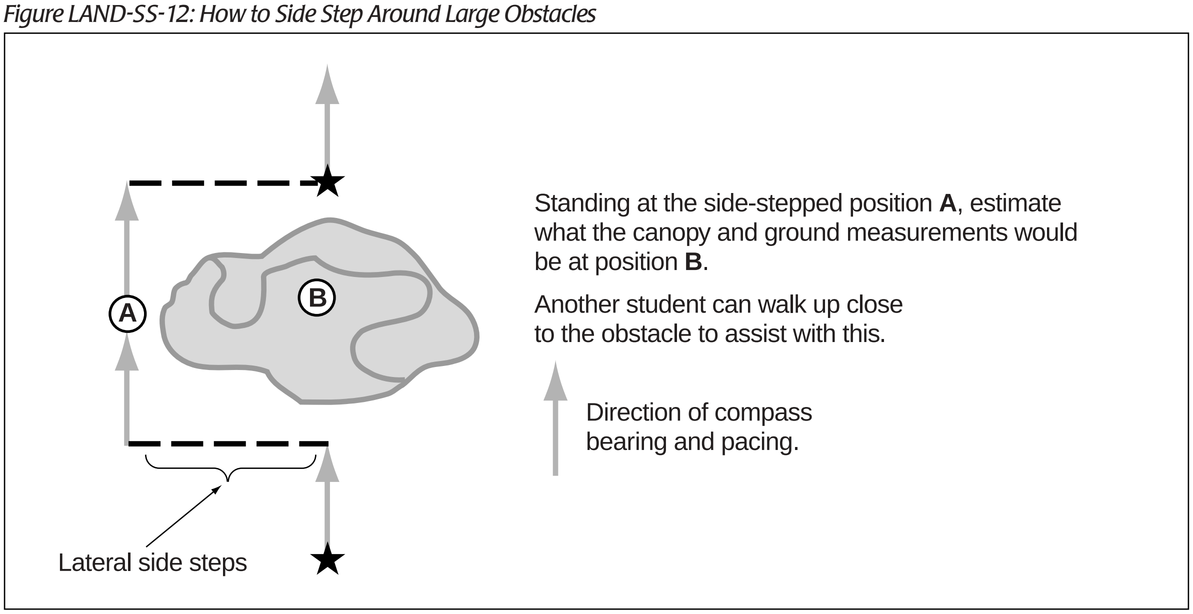
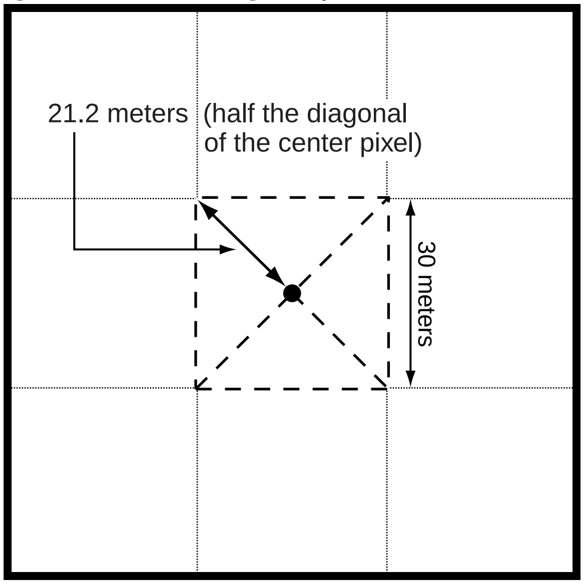


Figure LAND-SS-13: Pacing Example



while sidestepping and pacing around an obstacle, then estimate the reading from the sidestepped position.

- If an object is too large to conveniently side step, stop at the object and determine the direction you are pacing using your compass. Walk around the object until you are pacing in the same direction. Start counting again when you are going in the correct direction.

Determining the Number of Paces Required to Travel Half the Diagonal in a 30 m x 30 m Pixel

Note: If your students are able to divide using decimals, use the length of one of their paces to determine the number of paces in half a diagonal using the following formula:

$$\text{\# paces in half diagonal} = \frac{\text{21.2 meters}}{\text{length of one pace (meters)}}$$

If they cannot divide using decimals, use the procedure below.

1. Measure a distance of 21.2 meters (length of half the diagonal, see Figure LAND-SS-13) out on a flat, open area (a parking lot, field, or hallway is good).
2. Remember that one pace is two steps. Starting with your toe at the 0-meter mark, count the number of paces required to travel the entire distance using a normal stride.
3. Repeat this measurement three times and calculate the average to determine an average number of paces.
4. Round the number of paces that you calculate to the nearest half pace. This is the number of paces that it takes you to walk a half diagonal.
5. Record the number of paces required for each individual to walk a half diagonal so it can be referred to when collecting data at a Land Cover Sample Site.

Frequently Asked Questions

1. Why must I pace 21.2 meters?
21.2 meters is the distance of half the diagonal of a 30 m x 30 m area. This is the length that you will pace in each of four directions while taking biometry measurements.

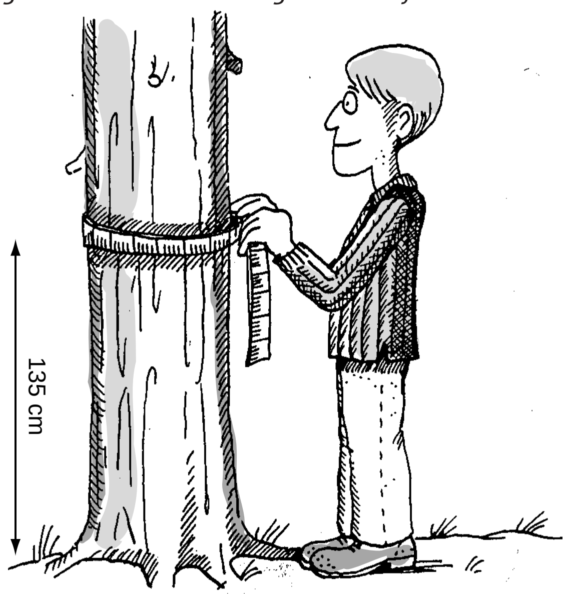
E. Tape Measure

You use a tape measure often when taking measurements at Land Cover Sample Sites. It is critical that you use the tape measure in the correct manner.

Directions for Reading a Tape Measure

Always use a metric tape measure.

Figure LAND-SS-14: Measuring Tree Circumference



Frequently Asked Questions

1. Why do we use the metric system?

The metric system is used for scientific investigations throughout the world.

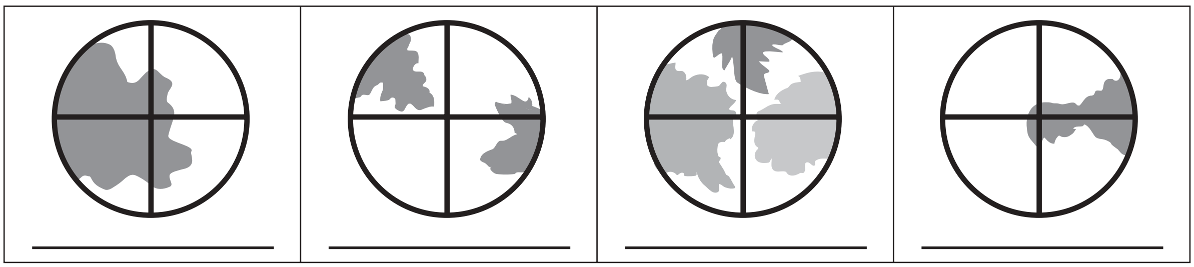
2. What if we only have a tape measure in English units (feet and inches)?

If you only have a tape measure in English units, you must convert all your measurements into metric units before reporting your data.

Investigation Instrument Assessment

The instruments in the previous sections are all important to carrying out the *Land Cover/Biology Investigation* accurately. Use the following assessment to gauge how well you understand the instruments and skills before going into the field. Answers to selected questions appear on the bottom of the page. If you are not able to perform these exercises or answer the questions, then review the relevant material in this section before proceeding to the field.

1. Demonstrate the correct way to hold the densiometer.
2. Below are several diagrams showing examples of what you might see when looking through the densiometer. Assuming that trees are overhead, label each diagram with a “T” or minus “-”.



3. What are the three measurements you must take in order to calculate the height of an object?
4. Stand at one end of the room and demonstrate how you would sight with your clinometer to measure the height of an object your teacher chooses. Have another student read the angle.
5. Measure the distance between you and the object your teacher chose for Number 4, take any other measurements you need and calculate the height of the object.
6. When you are measuring the height of a tree, you should look at the base of the tree and your feet, to be sure that they are
   ____.
7. Determine the number of paces it takes you to walk a distance of 15 meters. (Mathematically using your previous measurement or using the tape measure on the floor).
8. What is the minimum height for a tree?
9. At what height from the ground do you measure the circumference of a tree? Where is this (using your body as a reference)?

1) student should hold the densiometer vertically over his or her head so the washer is straight down 2) +, -, -, + 3) height of your eyes above the ground, distance from you to the tree and angle to the top of the tree as sighted through the clinometer 4) student should look through the straw from the correct end of the clinometer, he or she should site the top of the object 5) all measurements listed in question 3 should be taken and used in the calculation (use the formula in the Clinometer section) 6) at the same elevation on level ground 7) various answers based on each student’s pace length 8) 5 meters 9) 135 cm, location on body varies based on each student’s height

Land Cover Sample Site Protocol

Purpose

To determine the major land cover type at a Land Cover Sample Site

Overview

Students classify a homogeneous land cover site by visually examining the site. If necessary, students take biometry measurements following the *Biometry Protocol* to support their choice of MUC classification. Students locate the site using a GPS receiver and photograph the site.

Student Outcomes

Students will learn how to scientifically describe and classify a Land Cover Sample Site.

Science Concepts

Physical Science
- Objects have observable properties that can be measured using tools.
- Position of an object can be located by reference to other objects.

Life Science
- Earth has many different environments that support different organisms.
- All populations living together and the physical factors with which they interact constitute an ecosystem.

Geography
- How to use maps (real and imaginary)
- The physical characteristics of place
- The characteristics and distribution of ecosystems

Scientific Inquiry Abilities

- Use appropriate field instruments and techniques to gather Land Cover Sample Site data.
- Make observations in order to determine the appropriate land cover type.
- Communicate the results of land cover classification to reach a consensus.
- Identify answerable questions.
- Conduct scientific investigations.
- Develop descriptions and predictions using evidence.
- Recognize and analyze alternative explanations.
- Communicate procedures, descriptions, and predictions.

Level

All

Time

20 – 60 minutes (excluding travel time) for each Land Cover Sample Site

Frequency

Collect data once for each Land Cover Sample Site but data can be collected as frequently as you choose.

Materials and Tools

- Compass
- GPS receiver
- Camera
- Pencil or pen
- Landsat TM images of your 15 km x 15 km GLOBE Study Site
- Local and topographic maps (if available)
- Aerial photos (if available)
- Local vegetation field guides
- *MUC Field Guide* or *MUC System Table* and *MUC Glossary of Terms*
- *GPS Protocol Field Guide* (from *GPS Investigation)*
- *Land Cover Sample Site Data Sheet*
- *Biometry Protocol* materials as needed
- 50 m tape measure
- Markers for permanent sites
- Clipboard

Preparation

Make copies of appropriate *Data Sheets*.

Review *Site Selection and Set-Up*.

Identify MUC classes that are applicable to your local area.

Select the site(s).

Prerequisites

Concepts and technique in *Leaf Classification Learning Activity*

Ability to use the *MUC System Table* and *MUC Glossary of Terms* and/or the *MUC Field Guide*

GPS Protocol

Ability to take appropriate biometry measurements from *Biometry Protocol*

Ability to pace

Ability to use a compass

Ability to use a camera

Land Cover Sample Site Protocol – Introduction

If that was you standing in the middle of the picture below, how would you describe what was around you? Are there trees? If so, what kind are they? Are there any shrubs? Is there vegetation on the ground? What kind it is? Is it alive or dead? Broad-leaved or grass-like? Are there any buildings or roads? Would the site look different if you were in a hot air balloon above it? If you went back to school and someone asked you what the site looks like, what terms would you use? If your friend from another country called and asked you to describe what you saw, what would you say to him or her? Would you change how you describe it? How would you tell someone where you were? Would you use the names of local roads? Your friends from other places might not know the roads. How could you tell them so they could find it on a map?

You may have used words such as evergreens, deciduous trees, grasses, and shrubs to describe what the site looks like. What do all of those words mean? Scientists need to use terms that mean the same things to other scientists. For example, to many scientists a forest has specific qualities. If scientists can agree on what a forest is, they know that they are talking about the same thing.

What if you had a way to describe what an area looks like in one term? The GLOBE Program uses a system called MUC for describing *homogeneous* land cover. A homogenous site is an area that has only one type of land cover on it. MUC stands for Modified UNESCO (United Nations Educational, Scientific and Cultural Organization) Classification. With MUC, you can describe a site with up to a four-digit class. When you use MUC all of GLOBE will know what you are talking about. The first level of MUC is chosen as if you are looking down on your site from a hot air balloon. After that, the higher levels are also from above but start to get more specific.

How do you describe where your site is? In GLOBE, all sites are located using a GPS (Global Positioning System) receiver. The GPS receiver tells you the latitude, longitude and elevation of where you are standing. This way, anyone can locate where you are on a map.

With your location and description of the land cover, you can tell others about your site. When you report your data, other scientists will know where you were and what it looked like. Scientists can use your data to make maps from satellite imagery and measure how accurate they are. Scientists rely on your data because they cannot personally *validate* what is on the ground. *Validation* is the process of seeing how close you are to the real value. In this protocol, it is how well a map represents what is actually on the ground.

Scientists cannot always go to a place and see what is on the ground. This is why your *metadata* are important to scientists. *Metadata* are important field observations and notes about the data. For Land Cover, this includes historical information, weather conditions, weather effects, and other observations about the site. Metadata can provide insight about an area that may not be clear in the image scientists are looking at.

Teacher Support

The Measurement

Perform the *Land Cover Sample Site Protocol* when you visit one of your Land Cover Sample Sites. The protocol guides you through the process of collecting data at a site and determining the land cover type.

The *Land Cover Sample Site Protocol* is the cornerstone of the *Land Cover/Biology Investigation.* Remote sensing scientists all over the world can use the land cover classification data that you and your students collect. You will also use these data to help map your 15 km x 15 km GLOBE Study Site. Additional Land Cover Sample Site data are used to verify the accuracy of the maps. You can also use these data when looking at the change detection maps that you create from two satellite images, one from the 1990's and one from the 2000's. Remote sensing scientists may use your data and photographs of Land Cover Sample Sites to map and assess the accuracy of maps of larger areas. They may use the scale of a city, county, state, province, region, country or continent, depending on their focus. The *Land Cover Sample Site Protocol* is a very simple process in comparison to its importance, but it must be carefully followed. See Figure LAND-SA-1.

Students and teachers classify a 90 m x 90 m homogeneous land cover site using the MUC System (by using the *MUC Field Guide* or *MUC System Table* and *MUC Glossary of Terms*) and record the latitude, longitude and elevation using a GPS receiver. Pictures are taken in the four cardinal directions for data quality purposes.

A *classification system,* like the MUC System, is one of the ways to communicate about similarities and differences. A classification system is a comprehensive set of classes used to group similar objects. It has four characteristics: *Labels and definitions* that are arranged in a *hierarchical* (multiple levels of classes) or branching structure. It is totally *exhaustive*, meaning there is a class for every data point and *mutually exclusive*, meaning there is one and only one appropriate class for every data point. By using MUC, a common "language" of land cover types, scientists will know exactly what land cover is on the ground in a specific place. MUC is a classification system that has an ecological basis, is useful for remotely sensed data, and follows international standards. By using this same system all over the world, it is easy for scientists to compare data for any place on Earth. Students may have to use the *Biometry Protocol* in order to discriminate between MUC classes. You and your students should be prepared for this.

Follow-Up to Report Data

- Compile the field data and report it to GLOBE.
- Develop or print two copies of the photos (one copy is for your school) and label each photo with your school ID, the Land Cover Sample Site Name and directional aspect (N, S, E or W).
- Follow the directions in the *How to Submit Photos and Maps* section of the *Implementation Guide* on how and where to submit these photos to GLOBE.

Supporting Measurements

Biometry Protocol
GPS Protocol (from *GPS Investigation)*

Student Preparation

Concepts and technique in *Leaf Classification Learning Activity*

Ability to use the *MUC System Table* and *MUC Glossary of Terms* and/or the *MUC Field Guide*

Ability to carry out *GPS Protocol*

Ability to make appropriate biometry measurements from *Biometry Protocol*

Ability to pace

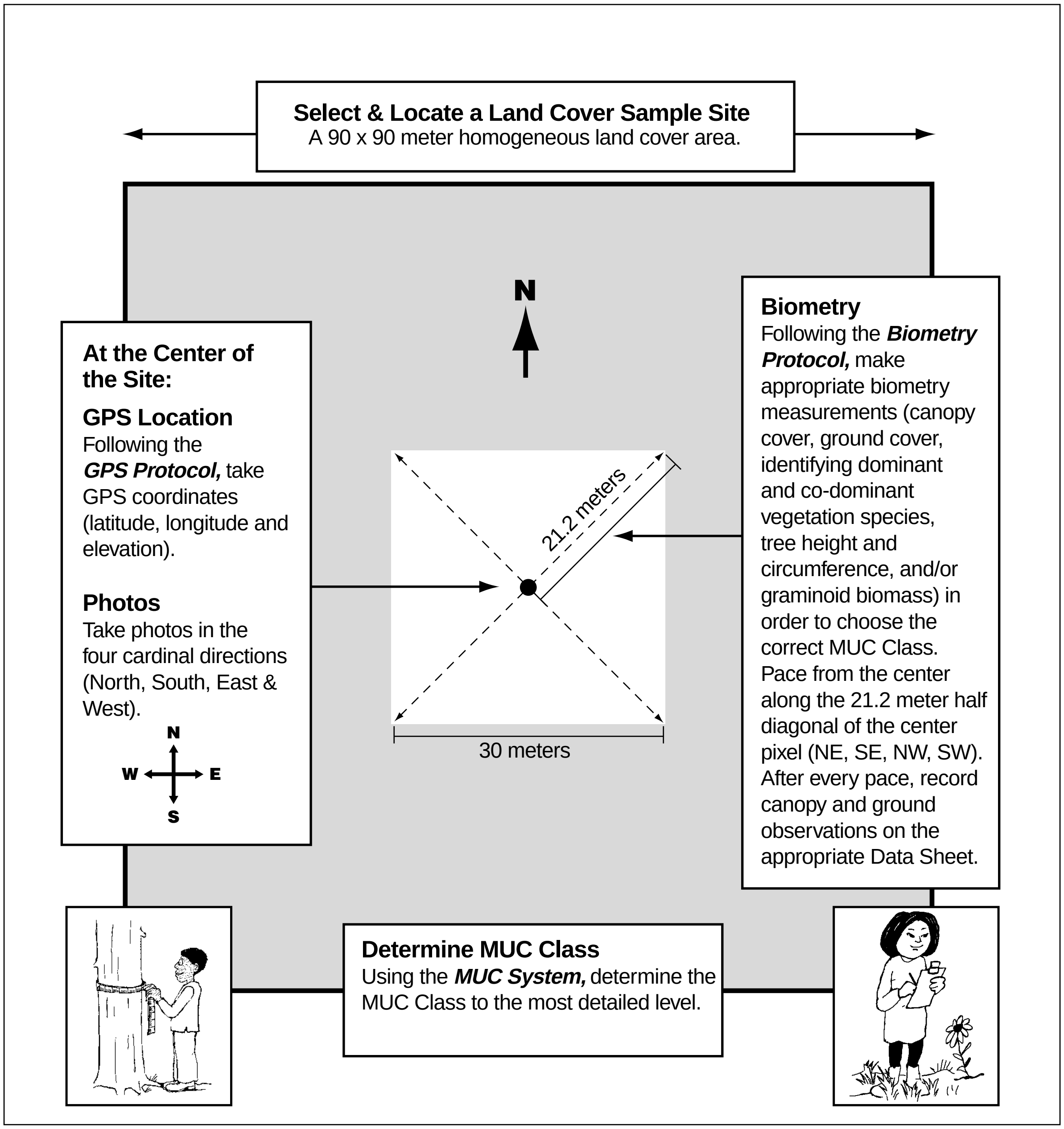
Ability to use a compass

Ability to use a camera

Helpful Hints

- Before going into the field, teach your students how to use your local vegetation field guides.
- Select the 90 m x 90 m area using the Landsat TM images and/or your local knowledge. Remember that it must have homogeneous land cover.

Figure LAND-SA-1: Land Cover Sample Site Protocol Overview



- In order to determine if your site is at least 90 m x 90 m have your students pace out 90 m from one of the corners of the site. They should pace in two directions, either North or South AND either East or West. This will give you an estimate of where two additional corners are. Estimate the location of the fourth corner. If the entire area is homogeneous, the site is appropriate. For instructions on *Pacing*, go to *Investigation Instruments.*
- Get help from local experts in plant identification or land cover mapping (e.g., botanists, foresters, horticulturists, surveyors).
- Take enough biometry measurements using the *Biometry Protocol* to accurately classify a land cover site.
- Your students should refer to the definitions in the *MUC Field Guide* or *MUC Glossary of Terms* when determining MUC for an area.
- Distinguishing among some MUC classes requires measurements of the percentage of your site that is covered by different types of vegetation. You can identify the appropriate MUC class by calculating the percentages of the vegetation types observed at the land cover site. Use the *Tree Canopy and Ground Cover Data Sheet.*

Questions for Further Investigation

What natural changes could alter the MUC class of these sites?

Is this MUC class typical for its latitude, longitude and elevation?

If someone only had photos of your site, what MUC class would he/she think this site is?

What other MUC classes are most similar to your site?

How will the land cover of your site affect local climate?

How will the land cover at your site affect your local watershed?

The Landsat TM image provided to your school may be several years old. If an image was acquired today, in what ways would it be different from your old one?

Does the nearest water body affect the vegetation of this site?

What types of animals do you think live here?

How are the land cover and soil characteristics of this site related?

How are the land cover and soil characteristics related?

Land Cover Sample Site Protocol

Field Guide

Task

Locate and photograph a Land Cover Sample Site and classify the land cover type according to the MUC System.

What You Need

- ❏ GPS
- ❏ Compass
- ❏ *MUC Field Guide* or *MUC System Table* and *MUC Glossary of Terms*
- ❏ Camera
- ❏ *Student Field Guide for GPS Protocol* and *GPS Data Sheet*
- ❏ *Land Cover Sample Site Data Sheet*
- ❏ Pencil or pen
- ❏ *Student Field Guides for Biometry Protocol* and materials (some sites)
- ❏ 50 m tape measure
- ❏ Local vegetation field guides
- ❏ Markers for permanent sites
- ❏ Clipboard

In the Field

1. Locate the approximate center of the 90 m x 90 m homogeneous site. **Note:** The site can be much larger than 90 m x 90 m as long as it is homogeneous.
2. Complete the top of the your *Sample Site Data Sheet* (School Name, Measurement Time, Recorded By, Site Name).
3. Identify the latitude, longitude and elevation of the center following the *Field Guide for GPS Protocol.* Record the average latitude, longitude and elevation from the *GPS Data Sheet* on the *Sample Site Data Sheet.*
4. Determine MUC class to the most detailed level using either the *MUC Field Guide* or the *MUC System Table* in combination with the *MUC Glossary of Terms*. Take any measurements necessary following the *Field Guides for Biometry Protocol* to help determine the class.
5. Note any unusual or helpful metadata. Record this in the appropriate place on your *Sample Site Data Sheet*.
6. Using the camera, take a photo in each cardinal direction – north, south, east and west. Use your compass to determine the directions. Record each photo number in the correct arrow on your *Data Sheet*.

Land Cover Sample Site – Looking at the Data

Are the data reasonable?

After collecting Land Cover Sample Site data, you should determine whether the types and locations of land cover are reasonable and accurate. For instance, if you are located in a mid-latitude temperate climate, does your data include land cover types only found in the equatorial tropical zone? Does it make sense to have land cover types only found in extremely dry desert-like areas? Do you have classes for mountainous areas when you are located in a coastal lowland? Ask yourself questions like these about the land cover types in your area. Check the MUC classes and definitions to determine whether the land cover classes you chose make sense for your GLOBE Study Site.

Next, think about where each of these land cover types are located. Using your knowledge of the area and other sources of information, like a print-out of your Landsat image, topographic maps and aerial photos (if available), do the locations of the land cover types make sense? If not, which land cover type(s) do(es) not make sense?

After looking at your data and seeing whether it is reasonable, you are now ready to compare your land cover types to other schools' land cover types. Graphs can help answer questions you might have thought of while you were collecting Land Cover Sample Site data. What is it like in other places? How does your data compare to other schools? Using the visualization pages of the GLOBE Web site, you can graph your data with data from other schools that have Land Cover Sample Sites similar to yours.

What do scientists look for in these data?

Land Cover Sample Site data is a "snapshot in time" of the land cover type in a particular area. These data can be used by anyone creating a map where land cover type is needed. Maps of habitat areas, topography, fire fuel amounts, urbanization, forest types, species locations, etc. use data such as GLOBE Land Cover Sample Site data for reference to create or assess a map. Students who collect Land Cover Sample Site data in a single area over a long period of time assist scientists in monitoring change over time in a region. In order for scientists to use GLOBE Land Cover Sample Site data, the MUC class must be as detailed as possible and have accurate GPS coordinates. The photographs that students take in the four cardinal directions are important for quality assurance.

An Example of Student Inquiry

Students from a school in Stockholm, Sweden had been collecting Land Cover Sample Site data for a few months. They did a search on the GLOBE Web site to see if other schools had also been collecting land cover data and found that one of their MUC classes was reported frequently by other schools. MUC 0192, Temperate and Subpolar Needle-Leaved Evergreen Closed Forest with Irregularly Rounded Crowns, was found in several states in the US, and other countries throughout the world. The students were curious to discover if there were correlations between the schools' latitudes, weather patterns and/or soil moisture readings. Each group in the class chose a different GLOBE measurement to research including latitude and elevation, temperature, precipitation and soil moisture. They hypothesized that MUC 0192 would be found in areas that had similar data to theirs.

In order to explore their hypothesis, the group that researched the temperature similarities first located the other schools that had submitted sites with the same MUC code, 0192. Using the GLOBE visualizations, they graphed one year's worth of temperature data for all the schools. Once all the data were graphed, they carefully studied any trends they saw. They also noted what the high and low temperatures were for each school and if they could determine if the school went through different seasons during the year. If a school had GLOBE temperature data from more than one year, they adjusted the graph to include that data also. They found that all the schools had a cold and warm season.

They wrote up their findings and made a display of the graph to be used in a presentation to the class. They looked forward to finding out if other groups had found trends in their data comparisons.

For a more detailed description of this activity, refer to the *Using GLOBE Data to Analyze Land Cover Learning Activity*.

Biometry Protocol

Purpose

To measure and classify the plant life present at a Land Cover Sample Site to help determine the MUC classification

Overview

Students walk the half-diagonals of their Land Cover Sample Site and take one or more biometry measurements. These may include canopy cover and ground cover, identifying dominant and co-dominant vegetation species, and measuring tree circumference and height, and/or graminoid biomass.

Student Outcomes

Students will learn how to use biological sampling techniques to quantify and describe a Land Cover Sample Site.

Science Concepts

Physical Science

Objects have observable properties that can be measured using tools.

Life Science

Earth has many different environments that support many different kinds of organisms.

Organisms change the environment in which they live.

All populations living together and the physical factors with which they interact constitute an ecosystem.

Geography

The physical characteristics of place

The characteristics and spatial distribution of ecosystems

Scientific Inquiry Abilities

Identify biometry measurements needed for MUC.

Use vegetation field guides to identify vegetation and species.

Interpret data to propose MUC classification.

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate procedures, descriptions, and predictions.

Level

All

Time

Variable, depending on type and number of measurements taken

Frequency

As necessary to determine MUC at most sites, or, frequently as an enrichment study

Materials and Tools

50 m tape measure

Compass

Species ID keys and/or other local species guides

MUC Field Guide or *MUC System Table* and *MUC Glossary of Terms*

Permanent tree markers (optional)

Pen or pencil

Calculator (optional)

Appropriate *Biometry Data Sheets*

Tubular densiometer (See *Investigation Instruments* section)

Clinometer (See *Investigation Instruments* section)
Flexible tape measure
Blindfold
Clipboard
Small bean bag
Grass clippers or strong scissors
Small brown paper bags
Drying oven
Balance or scale, accurate to 0.1 g

Preparation

Make copies of the appropriate *Work Sheets*.

Familiarize students with the MUC System.

Gather materials for clinometer and densiometer.

Have students practice taking field measurements, pacing and using a compass.

Prerequisites

Students make necessary field instruments.

Site-Seeing Learning Activity

Biometry Protocol – Introduction

Biometry is the measuring of living things. Why do scientists need measurements of living things? What do they tell us about our environment? The biometry measurements include tree height and circumference, canopy cover, ground cover, and *graminoid* biomass. Graminoids are grass and grass-like plants. These all measure the size or amount of trees and plants.

What do trees and plants store? What are they made of? Can *different* types of land cover have different size trees, shrubs or grasses? Can they have different amounts of trees, shrubs or grasses? Think about a desert. What is the most common tree or shrub there? Is that a sign of what kind of area it is? Compare that to the most common tree in a forest.

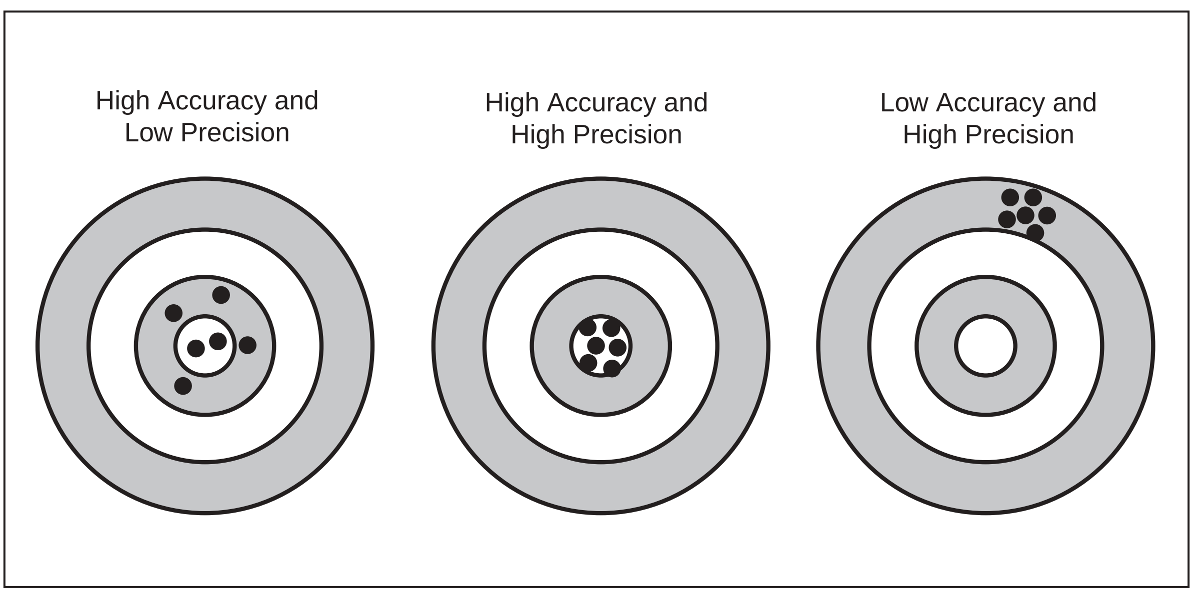
Can the *same* types of land cover have different size trees, shrubs or grasses? Can there be different amounts of trees, shrubs or grasses? Think about two wetlands. Are the trees, shrubs or grasses the same type and size in both areas?

Measurements of living things are important to scientists. They can show the amount of nutrients and gases living things store. They also show the amount of carbon and usable water stored in trees and plants.

Choosing the right MUC class can be hard. How do you know that you have a “deciduous forest” and not an “evergreen forest”? How do you know you are in a “shrubland” and not “woodland”? How do you know a site is “tall graminoid” and not “short graminoid”? Biometry measurements answer these questions.

Biometry measurements help you choose the right MUC class. What kinds of measurements will you need to decide between an evergreen and deciduous forest? What measurements will you need to decide if something is a shrub or a tree? What do you need to know to decide between a tall and short graminoid site?

Biometry measurements make your data more reliable. When scientists use your Land Cover Sample Site data, biometry measurements assure them that the data are of high quality. There are two tests of good measurement technique. Biometry measurements will help assess how close to the bull’s-eye (the right answer) your data are. This is called *accuracy*. Your data are *precise* when you repeat measurements and get the same results throughout a site. The goal of GLOBE students should be to have their measurements look like the bull’s eye in the center (see below), highly accurate and precise! Biometry measurements can help you do that.



Teacher Support

The Measurement

The *Biometry Protocol* is divided into four different measurements: canopy and ground cover, tree, shrub and/or graminoid height, tree circumference and graminoid biomass. You may choose to take biometry measurements only once in a site during peak growth, or you can return to the same site year after year and repeat the biometry measurements to track changes in the site biomass over time. You may also take biometry measurements twice a year in a single site year after year, once during peak foliage or growth and once during a time of low growth (i.e. winter or drought). You should always use the following two guidelines to determine what measurements you should take:

First, take ANY measurements necessary to determine the correct MUC class. Whenever a decision must be made between MUC classes, take the appropriate biometry measurement (i.e. canopy and ground cover or height) to make that decision. If the decision can be made without biometry measurements, it is not necessary to take any, but you may choose to do so to ensure accuracy.

Second, scientists will be using an aerial view when using the MUC and biometry data and you should too. Therefore, measurements of the dominant land cover in the highest canopy are the most important. Canopy cover refers to the upper layer of vegetation detected by satellite sensors. For instance, in a forest where there are tall trees covering the entire site, shrubs scattered throughout the site below the trees and some tall grasses on the forest floor, the biometry measurement that would be most important would be canopy and ground cover and tree height. You may choose to measure shrub height or graminoid biomass but since a satellite image would only portray the tree canopy, these data would be less important. Another example would be in herbaceous vegetation sites. If the area was primarily graminoid with two trees and several shrubs, the most useful biometry measurement would be graminoid biomass. (**Note:** If you use the canopy and ground cover measurement to determine the MUC class, report that measurement also.) You can also measure the height of the shrubs and trees but since they are not the dominant land cover, the graminoids would dominate the satellite image in that area.

Student Preparation

Students should be able to define and identify a homogeneous land cover site.

Students should understand and know how to classify a site using the MUC System.

Students should make and know how to use the densiometer and clinometer.

Students should know how to use a compass.

Students should practice pacing techniques. They should know their pace and how many paces are in 21.2 meters.

Helpful Hints

- Practice these measurements in a location close to school to get some experience before using them in a Land Cover Sample Site.
- You or your students may want to investigate a potential site with a brief visit to make sure that it is large enough and homogeneous throughout before a longer data collection visit.
- When distinguishing between trees and shrubs, use the definition of a tree given in the *MUC Field Guide* and *MUC Glossary of Terms:* a tree is at least 5 meters tall. You may want to practice estimating this height with the clinometer near your school before entering the field.
- If the shrub canopy is below the observer, treat it as ground cover. Dwarf-shrubs are always considered ground cover.
- It is more efficient to have your students work in pairs or trios for this protocol.
- For more accurate readings, other pairs of students should repeat the measurements. If different teams of students repeat observations, report the average of these values if they generally agree.
- Before going into the field, teach your students how to use your local vegetation field guides.
- It is recommended that you consult local experts (Forest Service, County Extension Agent, etc.) to assist with species identification.
- If your site experiences seasonal variation and you choose to track changes in biomass over time, take biometry measurements once during peak growing season and once during the least active season.
- If it takes smaller students more than forty paces to complete a diagonal, they may take measurements at every other pace.
- For younger students, if the angle on the clinometer is 45 degrees, the distance from the tree will equal the height of the tree above the student's eye level. See the *Alternative Technique to Measure Tree Height on Level Ground: Simplified Clinometer Technique Field Guide.*
- If you are going to revisit a forest or woodland site, mark and number/label the trees you use. Always measure the same trees, and report their heights and circumferences in the same order.
- Examples of forbs include clover, sunflowers, ferns, and milkweeds.
- Do not use a conventional oven to dry the graminoid vegetation. This is dangerous because the oven may have to be left on continuously for several days!
- In warm, dry climates, graminoid biomass samples can be dried in mesh bags outside.
- Make sure to use several small brown drying bags for proper drying of graminoid samples.
- If you are performing the *Canopy Cover* and *Ground Cover* measurements with a class, break the class into groups and have each group pace a different half-diagonal. Each group will need their own copy of the *Field Guide,* a *Data Sheet,* and a densiometer. Ideally, one person should serve as a 'pacer' and one should be the 'recorder.' The 'pacer' walks the distance and makes the measurements. The 'recorder' records the readings onto the *Data Sheet* and makes sure the 'pacer' is walking straight in the assigned direction. The 'pacer' should know how many of his/her paces are in the 21.2 m length of the half-diagonal. Have each student write this number on their copy of the *Field Guide.* This is the total number of measurements/paces to take in walking a half-diagonal from the center to the corner of the central 30 m x 30 m area.

Questions for Further Investigation

What are the dominant and co-dominant species in your Land Cover Sample Site? Do these species always occur in sites that have the same MUC class?

Are the dominant and co-dominant species common in your area? Are these species native to your area? Are the trees mature or juvenile?

Is there a relationship between the amount of ground cover and canopy cover?

Are the percentages of the canopy and ground cover consistent with your MUC class?

Which is greater, the amount of brown or green ground cover? Do you think that these amounts will change during the year?

If your MUC 4 site has trees as the co-dominant species: Is the herbaceous vegetation around the trees the same as that in open areas?

Canopy Cover and Ground Cover
Field Guide

Task

Take ground and canopy cover measurements while pacing half-diagonals to determine the MUC class of your Land Cover Sample Sites.

What You Need

❑ Tubular densiometer

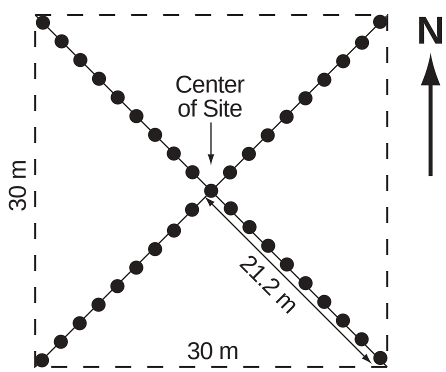
❑ *Canopy and Ground Cover Data Sheet*

❑ Pen or pencil

❑ Compass

❑ Species ID keys and/or other local species guides

❑ Clipboard



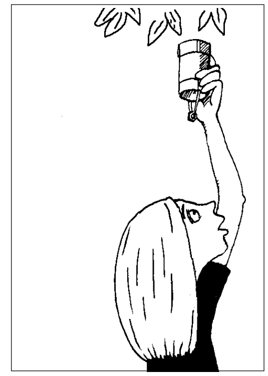
The central 30 m x 30 m area of a Land Cover Sample Site with the four 21.2 m half-diagonals (in the NE, SE, SW and NW directions) for sampling.

In the Field

1. Locate the center of your homogeneous Land Cover Sample Site. This is your starting point.
2. Choose a direction in which to walk: NE, NW, SE, or SW. Use a compass for bearing.
3. Look up through your densiometer. Be sure the metal nut or washer is directly below the crosshairs at the top of the tube. In column 1 of the *Canopy and Ground Cover Data Sheet* record:
   "-" if you see sky above the crosshairs

   "T" if you see leaves, twigs, or branches at the crosshairs and they are attached to a tree (greater than 5 meters tall)

   "SB" if you see leaves, twigs or branches at the crosshairs and they are attached to a shrub (a woody plant between 50 cm and 5 meters tall)



4. In column 2 of the *Canopy and Ground Cover Data Sheet* record:

   "-" if you see sky above the crosshairs

   "E" if the tree or shrub you see is evergreen

   "D" if the tree or shrub you see is deciduous

5. Stand with your feet shoulder-width apart. Look down and observe any vegetation that is touching your feet or legs below the knee. In column 3 of the *Canopy and Ground Cover Data Sheet* record:

   "-" if there is no vegetation

   "B" if there is brown vegetation (still attached to the ground)

   "G" if there is green vegetation and in column 4 identify the type of green vegetation

6. In column 5 of the *Canopy and Ground Cover Data Sheet* record the species name or common name of the tallest tree or shrub you have observed at this spot.

7. In column 6 of the *Canopy and Ground Cover Data Sheet* record:

   "+" if the tallest vegetation is a shrub

   "-" if the tallest vegetation is not a shrub

8. In column 7 of the *Canopy and Ground Cover Data Sheet* record:

   "+"if the tallest vegetation is a dwarf shrub

   "-" if the tallest vegetation is not a dwarf shrub

9. Take a pace (two steps) in the direction you are going. Repeat steps 3 to 8. Stop when you have gone 21.2 meters and reached the corner of your sample area.

10. Repeat steps 2 to 9 for another direction until all four are measured or share your data with other students who have paced the other diagonals of your sample area.

11. Complete the tables at the bottom of page 2 of the *Canopy and Ground Cover Data Sheet* using the total data collected from all four diagonals. Calculate the percentages indicated.

12. Use these data to help determine or confirm your choice of a MUC classification and to determine dominant and co-dominant species for your site. Report these data to GLOBE.

Determining the percentage tree canopy cover:

$$\% \text{ Tree Cover} = \frac{\text{Total "T" Canopy Observations}}{\text{Total Observations}} \times 100$$

Determining the percentage evergreen canopy cover:

$$\% \text{ Evergreen Cover} = \frac{\text{Total "E" Canopy Type Observations}}{\text{Total Observations}} \times 100$$

Determining the percentage deciduous canopy cover:

$$\% \text{ Deciduous Cover} = \frac{\text{Total "D" Canopy Type Observations}}{\text{Total Observations}} \times 100$$

Determining the percentage graminoid canopy cover:

$$\% \text{ Graminoid Cover} = \frac{\text{Total "GD" Ground Vegetation Type Observations}}{\text{Total Observations}} \times 100$$

Determining the percentage shrub canopy cover is more complicated. If shrubs occur under trees, the canopy cover is tree not shrub.

$$\% \text{ Shrub Cover} = \frac{\text{Total Observations where Shrubs are the tallest vegetation}}{\text{Total Observations}} \times 100$$

Determining the percentage dwarf shrub canopy cover is also more complicated. If dwarf shrubs occur under trees or shrubs, the canopy cover is tree or shrub and not dwarf shrub.

$$\% \text{ Dwarf Shrub Cover} = \frac{\text{Total Observations where Dwarf Shrubs are the tallest vegetation}}{\text{Total Observations}} \times 100$$

Graminoid, Tree and Shrub Height

Field Guide

Task

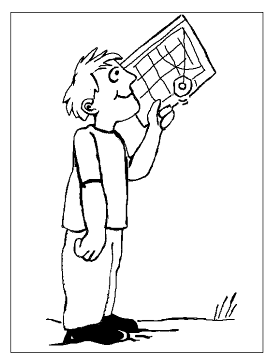
Measure the height of graminoid vegetation, shrubs and/or trees to help determine the MUC class of your Land Cover Sample Site.

What You Need

- ❏ 50 m measuring tape
- ❏ Flexible measuring tape
- ❏ Small bean bag
- ❏ *Graminoid, Tree, and Shrub Height Data Sheet*
- ❏ Pen or pencil
- ❏ Permanent tree markers (optional)
- ❏ Clinometer
- ❏ Species ID keys and/or other local species guides
- ❏ Blindfold

In the Field

1. Measuring Graminoid Vegetation Height (Graminoids are grass-like species.)
   a. Stand in the center of your Land Cover Sample Site and blindfold your partner. Have him or her throw a beanbag somewhere in the site.
   b. Using the flexible measuring tape, measure the height of the herbaceous vegetation where the beanbag landed. Measure from the ground to the top of the graminoids.
   c. Record the height on the *Graminoid, Tree, and Shrub Height Data Sheet.*
   d. Repeat this process two more times and average the results.
   e. Use this average to determine your MUC class.



2. Measuring Shrub Height (Shrubs are 0.5 m to 5.0 m tall.)
   a. Stand in the center of your Land Cover Sample Site and blindfold your partner. Have him or her throw a beanbag somewhere in the site.
   b. Locate the closest shrub to the beanbag. Measure the height of the shrub from the ground to the tallest branch. Do this with a tape measure if possible. If the shrub is too tall, measure it with your clinometer using the directions for *Measuring Tree Height* in the next section.
   c. Record the height on the *Graminoid, Tree, and Shrub Height Data Sheet.*
   d. Repeat this process two more times and average the results.
   e. Use this average to determine your MUC class.

3. Measuring Tree Height (Hint: Trees are greater than 5.0 m tall.)

   a. Determine your dominant (most common) and co-dominant (second-most common) tree species by counting the number of times each tree species was recorded on the *Canopy and Ground Cover Data Sheet*. Record the names of the species on your *Graminoid, Tree and Shrub Height Data Sheet.*

   b. Choose:

      • the tallest tree of the dominant species

      • the shortest tree of the dominant species that still reaches the canopy

      • three trees that have heights in between the tallest and shortest of the dominant species

   c. Permanently mark and number/label the trees if your teacher has instructed you to do so or if you will be returning to this site to take measurements over time.

   d. Measure the height of the tree using the clinometer. If you are on ground with a slope, or using the simplified clinometer technique, then use the appropriate *Alternative Technique to Measure Tree Height Field Guide* to substitute for the steps below. Otherwise,

      • Move away from the base of the tree until you can see the top of the tree through the drinking straw of the clinometer.

      • For the best results, adjust your distance from the base of the tree so that the clinometer reads as close to 30˚ as possible and you are at least as far from the tree as it is tall.

      • Be sure to be on level ground so that your feet are at the same elevation as the base of the tree. Remember, if you are not on the same level with the tree, you need to use an *Alternative Technique to Measure Tree Height Field Guide*.

      • Have your partner read and record the number of degrees (˚) of the angle.

      • Using the *Table of Tangents,* record the TAN of the angle on the *Data Sheet.*

      • Measure the distance between you and the tree. Have your partner help you using the 50 m tape. Record this in the table on your *Data Sheet*.

      • Measure the height from the ground to your eye level. (You only need to do this step once!) Record this in the table.

      • Calculate the tree height using the following formula:

        Height of Tree = TAN (angle of clinometer) x (distance to tree) + eye height

        and record on your *Data Sheet.*

      • Measure the height of each tree three times and calculate the average of the three heights. If they are within one meter, record the average on your *Data Sheet.* If not, repeat the measurements until they are within one meter.

e. Repeat the step above for the other four trees.

f. If your co-dominant species is a tree, repeat steps b-e for the co-dominant tree species. If you do not have five co-dominant species trees on your site, include other tree species to make a total of five. Note that you are using other species in the *Metadata.*

Tree Circumference
Field Guide

Task

Make circumference measurements for your selected dominant and co-dominant trees. Use the same trees you measured for tree height (in the same order).

What You Need

❑ Flexible measuring tape

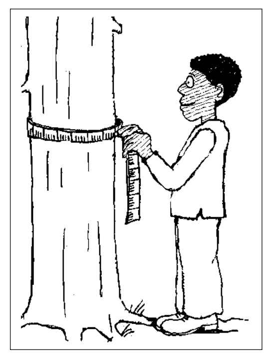
❑ *Tree Circumference Data Sheet*

❑ Pen or pencil

❑ Species ID keys and/or other local species guides

In the Field

1. With the flexible tape measure, measure from the ground at the base of the tree to a height of 1.35 m up on the tree (called Breast Height).
2. Measure the circumference in *centimeters* at Breast Height.
3. Record this on the *Tree Circumference Data Sheet*.
4. Repeat this for each of the trees you measured for height.



Graminoid Biomass

Field and Lab Guide

Task

Measure Graminoid Biomass in Land Cover Sample Sites. **Note:** Graminoid refers to grass-like vegetation only.

What You Need

- ❑ Small bean bag
- ❑ *Graminoid Biomass Data Sheet*
- ❑ Pen or pencil
- ❑ Blindfold
- ❑ Grass clippers or strong scissors
- ❑ Small brown paper bags
- ❑ Species ID keys and/or other local species guides
- ❑ Balance

In the Field

1. Blindfold your partner and have him or her throw a beanbag somewhere in the site.
   a. Mark a one-meter square around the beanbag to take a random sample.
   b. Using the garden clippers, clip all the vegetation close to the ground within the square. Do not collect any unattached leaves or litter.
   c. Sort the clippings into green and brown portions. Any clipping with even a little green is considered green.
   d. Place the green and brown portions into separate brown paper bags. Label the bags as your teacher directs you.
2. Repeat step 1 two more times.

In the Classroom

3. Calculating Graminoid Biomass:
   a. Check the temperature of the drying oven, it should read between 50 and 70 degrees Celsius.
   b. Put the labeled bags in the drying oven.
   c. Use a balance to measure the mass (g) of each bag once a day.
   d. When the mass is the same two days in a row, the samples are completely dry.
   e. Record the mass of each bag and its contents on the *Graminoid Biomass Data Sheet*.
   f. Shake out the contents of one bag and weigh the empty bag. Record this mass. Repeat this step for each bag.
   g. Calculate the mass of the graminoid vegetation (graminoid biomass) using the following formula:

$$\boxed{\text{Graminoid Biomass} = \text{Mass of Sample and Bag} - \text{Mass of Empty Bag}}$$

   h. Record the graminoid biomass of each sample on the *Graminoid Biomass Data Sheet*.

Measure Tree Height on Level Ground: Simplified Clinometer Technique

Field Guide

Task

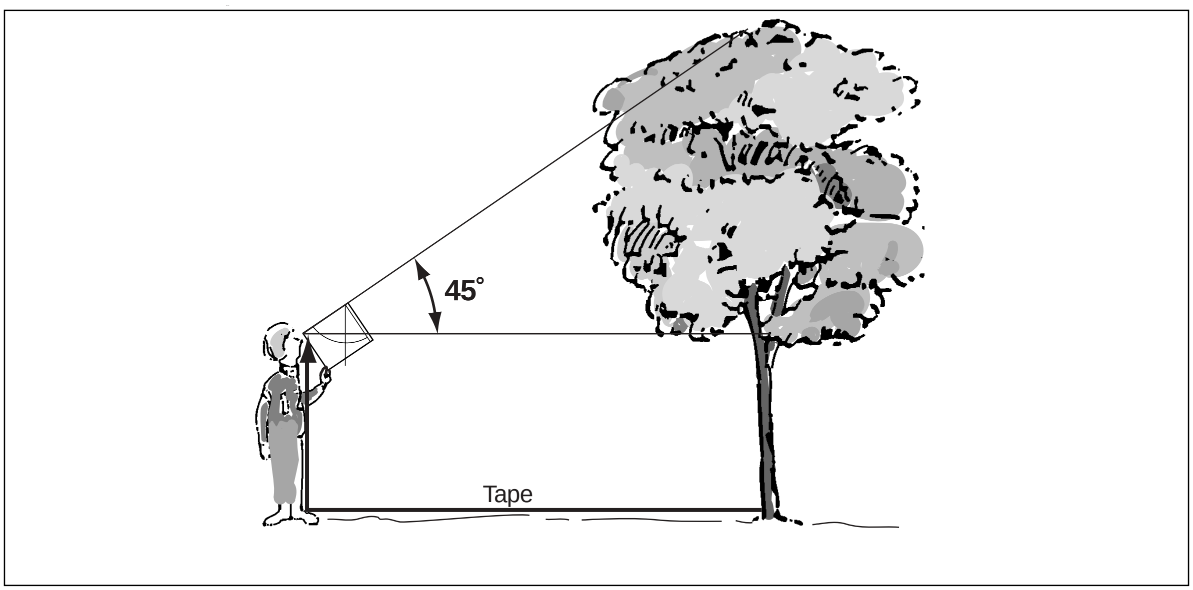
Measure heights of shrubs and/or trees to help determine the MUC class of your Land Cover Sample Sites.

What You Need

- ❏ 50 m measuring tape
- ❏ Flexible measuring tape
- ❏ Small bean bag
- ❏ *Measure Tree Height on Level Ground: Simplified Clinometer Technique Data Sheet*
- ❏ Pen or pencil
- ❏ Permanent tree markers (optional)
- ❏ Clinometer
- ❏ Species ID keys and/or other local species guides
- ❏ Blindfold

In the Field

1. Work in a team of two or three. Move away from the base of the tree until the clinometer reads 45 degrees when you see the top of the tree through the straw.
2. Have your partner stretch the 50 m measuring tape from the base of the tree to your toes. Your partner should then step on the tape at the ground and then run it up to your eye level.
3. This is the height of the tree. Record this on the *Measure Tree Height on Level Ground: Simplified Clinometer Technique Data Sheet.*
4. Repeat steps 1-3 two more times for each tree and report the average value.



Measure Tree Height on a Slope: Stand by Tree Technique

Field Guide

Task

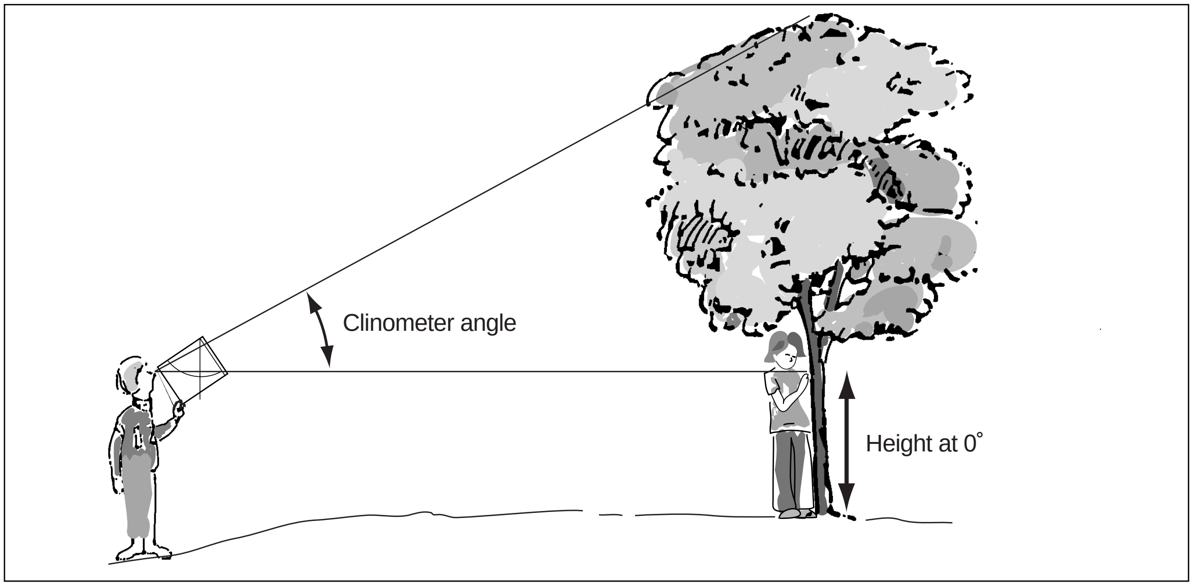
Measure heights of shrubs and/or trees to help determine the MUC class of your Land Cover Sample Sites.

What You Need

- ❑ 50 m measuring tape
- ❑ Flexible measuring tape
- ❑ Small bean bag
- ❑ *Measure Tree Height: Stand by Tree Technique Data Sheet*
- ❑ Pen or pencil
- ❑ Permanent tree markers (optional)
- ❑ Clinometer
- ❑ Species ID keys and/or other local species guides
- ❑ Blindfold

In the Field

1. Work in a team of three. One person stays by the tree. You and another partner move away from the base of the tree until you can see the top of the tree through the drinking straw of the clinometer. **Note:** For the best results, adjust your distance so that the clinometer is as close to 30 degrees as possible and you are further from the tree than it is tall.
2. Site the top of the tree using the clinometer. Have your partner read and record the clinometer angle.
3. Using the *Table of Tangents*, record the TAN of the angle on the *Measure Tree Height: Stand by Tree Technique Data Sheet.*
4. Keeping the clinometer at 0 degrees, look through the straw and have your partner by the tree locate the position on the tree that you see.
5. Measure the height from the base of the tree to the position on the tree that you see when the clinometer reads 0 degrees.
6. Measure the distance between you and the tree. Have your partner help you using the 50 m tape. Record this in the *Measure Tree Height: Stand by Tree Technique Data Sheet.*



7. Calculate the tree height using the following formula:

   [TAN (Angle of the Clinometer) x (Distance to Tree)] + (Height to 0 Degrees on Tree)

8. Record the tree height in the *Measure Tree Height: Stand by Tree Technique Data Sheet.*

9. Repeat steps 1-8 two more times for each tree and report the average value

Measure Tree Height on a Slope: Two-Triangle with Feet Higher than Tree Base Technique

Field Guide

Task

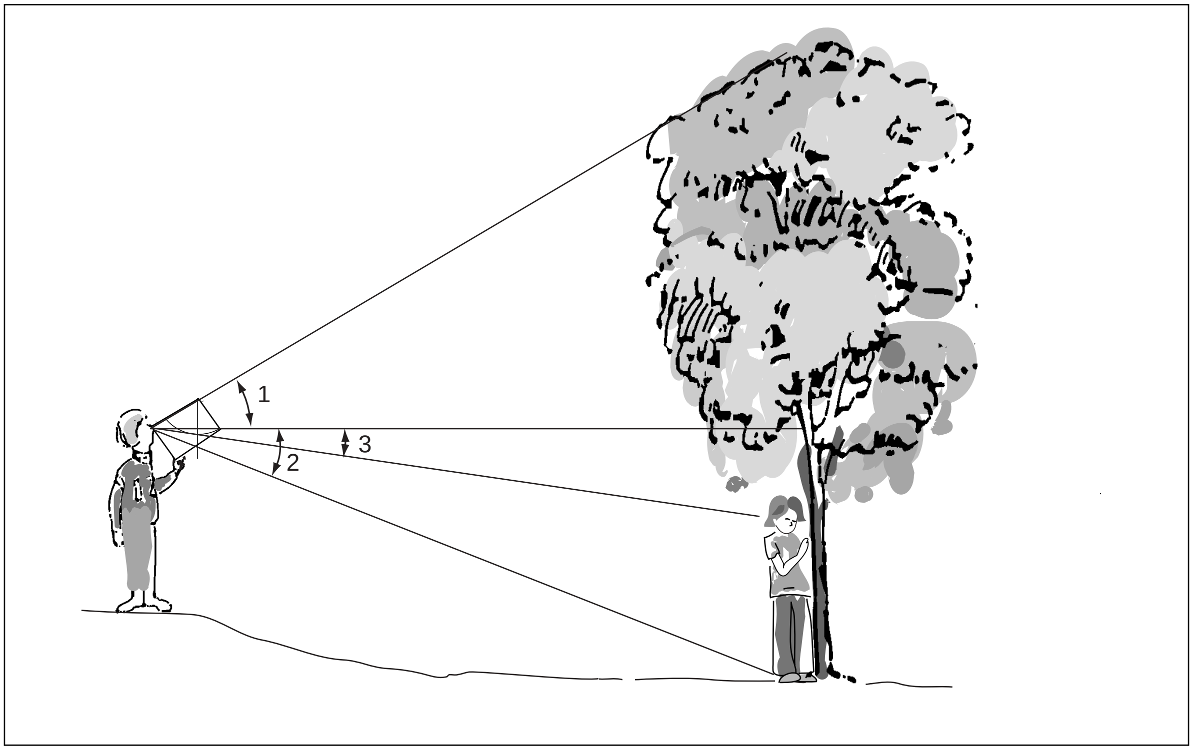
Measure heights of shrubs and/or trees to help determine the MUC class of your Land Cover Sample Sites.

What You Need

- ❑ 50 m measuring tape
- ❑ Flexible measuring tape
- ❑ Small bean bag
- ❑ *Measure Tree Height on a Slope: Two-Triangle with Feet Higher than Tree Base Technique Data Sheet*
- ❑ *Table of Cosines*
- ❑ Pen or pencil
- ❑ Permanent tree markers (optional)
- ❑ Clinometer
- ❑ Species ID keys and/or other local species guides
- ❑ Blindfold

In the Field

1. Work in a team of three. Two of you should be about the same height. You and another partner move away from the base of the tree until you can see the top of the tree through the drinking straw of the clinometer. **Note:** For the best results, adjust your distance so that the clinometer is as close to 30 degrees as possible and you are further from the tree than it is tall.
2. Site the top of the tree using the clinometer. Have your partner read and record the clinometer angle. This is ∠ 1.
3. Using the *Table of Tangents*, record the TAN of the angle on the *Measure Tree Height on a Slope: Two-Triangle with Feet Higher than Tree Base Technique Data Sheet.*
4. Turn the clinometer around and look through the straw through the opposite end. Site the base of the tree. Have your partner read and record this clinometer angle. This is ∠ 2.
5. Using the *Table of Tangents*, record the TAN of the angle on the *Measure Tree Height on a Slope: Two-Triangle with Feet Higher than Tree Base Technique Data Sheet.*
6. Have your partner who is about your height stand by the tree. Site your partner's eyes through the straw of the clinometer. Your other partner reads and records this clinometer angle. This is ∠ 3.
7. Using the *Table of Cosines*, record the COS of the angle on the *Measure Tree Height on a Slope: Two-Triangle with Feet Higher than Tree Base Technique Data Sheet.*



8. Measure the horizontal distance from you to the base of the tree. Have your partner help you using the 50 m tape. Record this in the *Measure Tree Height on a Slope: Two-Triangle with Feet Higher than Tree Base Technique Data Sheet.*
9. Calculate the Baseline using the following formula:

   (Distance to the Tree) x COS (Angle to Partner's Eyes)
10. Calculate the tree height using the following formula:

    TAN (1st Angle of the Clinometer) x (Baseline) + TAN (2nd Angle of the Clinometer) x (Baseline)
11. Record the tree height in the *Measure Tree Height on a Slope: Two-Triangle with Feet Higher than Tree Base Technique Data Sheet.*
12. Repeat steps 1-11 two more times for each tree and report the average value.

Measure Tree Height on a Slope: Two-Triangle with Feet Lower than Tree Base

Field Guide

Task

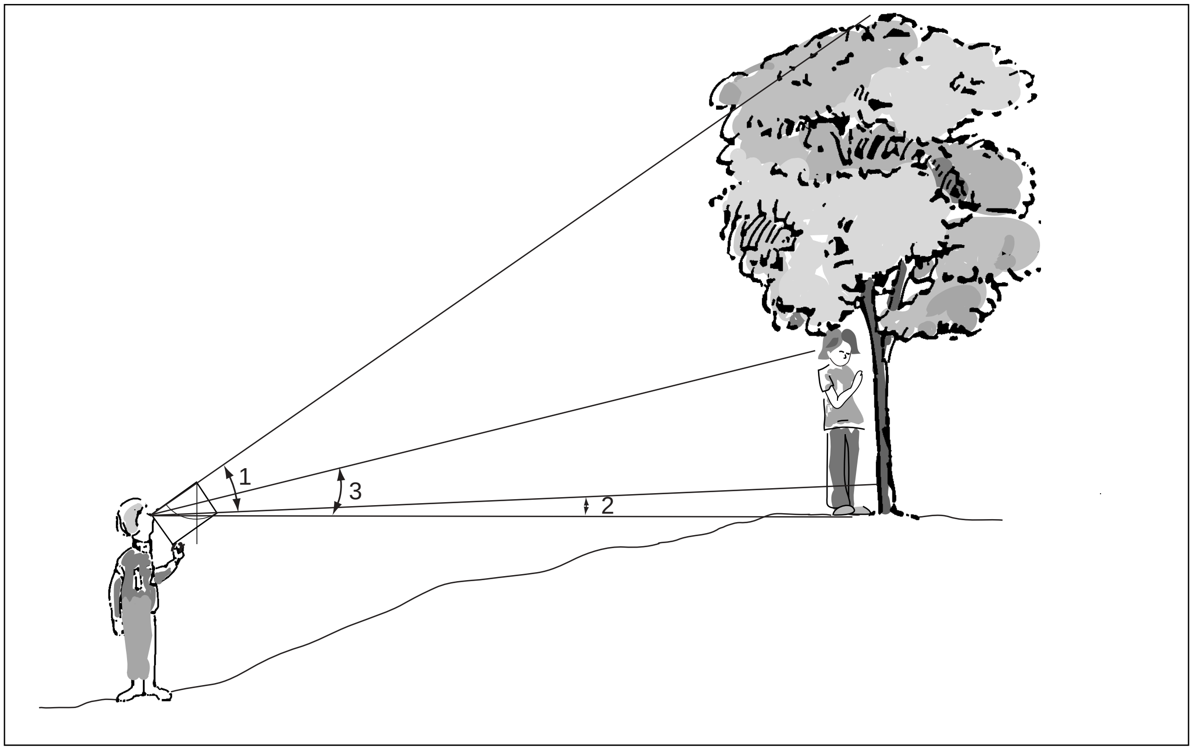
Measure heights of shrubs and/or trees to help determine the MUC class of your Land Cover Sample Sites.

What You Need

- ❑ 50 m measuring tape
- ❑ Flexible measuring tape
- ❑ Small bean bag
- ❑ *Measure Tree Height on a Slope: Two-Triangle with Feet Lower than Tree Base Data Sheet*
- ❑ *Table of Cosines*
- ❑ Pen or pencil
- ❑ Permanent tree markers (optional)
- ❑ Clinometer
- ❑ Species ID keys and/or other local species guides
- ❑ Blindfold

In the Field

1. Work in a team of three. Two of you should be about the same height. You and another partner move away from the base of the tree until you can see the top of the tree through the drinking straw of the clinometer. **Note:** For the best results, adjust your distance so that the clinometer is as close to 30 degrees as possible and you are further from the tree than it is tall.
2. Site the top of the tree using the clinometer. Have your partner read and record the clinometer angle. This is ∠ 1.
3. Using the *Table of Tangents*, record the TAN of the angle on the *Measure Tree Height on a Slope: Two-Triangle with Feet Lower than Tree Base Data Sheet.*
4. Site the base of the tree using the clinometer. Have your partner read and record this clinometer angle. This is ∠ 2.
5. Using the *Table of Tangents*, record the TAN of the angle on the *Measure Tree Height on a Slope: Two-Triangle with Feet Lower than Tree Base Data Sheet.*
6. Have your partner who is about your height stand by the tree. Site your partner's eyes through the straw of the clinometer. Your other partner reads and records this clinometer angle. This is ∠ 3.
7. Using the *Table of Cosines*, record the COS of the angle on the *Measure Tree Height on a Slope: Two-Triangle with Feet Lower than Tree Base Data Sheet.*



8. Measure the horizontal distance from you to the base of the tree. Have your partner help you using the 50 m tape. Record this in the *Measure Tree Height on a Slope: Two-Triangle with Feet Lower than Tree Base Data Sheet.*
9. Calculate the Baseline using the following formula:

   (Distance to the Tree) x COS (Angle to Partner's Eyes)
10. Calculate the tree height using the following formula:

    TAN (1st Angle of the Clinometer) x (Baseline) – TAN (2nd Angle of the Clinometer) x (Baseline)
11. Record the tree height in the *Measure Tree Height on a Slope: Two-Triangle with Feet Lower than Tree Base Data Sheet.*
12. Repeat steps 1-11 two more times for each tree and report the average value.

Frequently Asked Questions

1.We have a MUC 0; however, no particular species is dominant. What should we do?
In your metadata, record that you have a mix of species for the dominant species and what those species are in the metadata. If you take tree height and circumference measurements, use the same criteria for selecting the trees but report the canopy as "mixed."

2. What should we do if there is a multi-storied canopy?
If there is a multi-story canopy, try to identify the highest level of the canopy without changing your position. If the vegetation touches the intersection of the crosshairs, mark a (+).

3. What if the entire circle I see through the densiometer is full of vegetation, but there is no vegetation at the crosshairs?
This is a sampling question. The Land Cover/Biology Team has chosen the intersection of the crosshairs as the sample. Therefore, this would be a (–).

4. What if we can't get to our site during peak vegetation (full leaf-on) conditions?
If you cannot get to your site during peak growth (leaf-on), measure your site during the leaf-off period and try your best to get the peak growth (leaf-on) data, when you can.

5. What if my students are too young to understand the math used to determine tree height?
Use the *Simplified Technique for Measuring Tree Height on Level Ground.*

6. What if I want to measure the heights of trees on a slope?
There are additional guides for these situations that provide different methods to measure the heights of trees on slopes. The one you choose depends on the topography of your site.

7. What if the tree is leaning?
If the tree is leaning, just measure to the top of the tree as usual. Measure the baseline distance to a point directly below the highest point of the canopy, which may not be where the trunk of the tree meets the ground.

8. What if the canopy cover is thick and I cannot clearly see the top of individual trees?
A very thick canopy often occurs in areas where many of the trees are very close in height. You may have to move around your area to find a good sight-line to the tops of your trees.

9. How accurate is measuring tree heights?
Like any other measurement, accuracy and precision increase with practice and the use of care in the measurement. Three groups measuring the same tree should get results within +/- 1 meter of each other.

10. What do I do if I do not have a single co-dominant tree or shrub species?
If the co-dominant species is mixed at your site, measure the heights and circumferences for 5 trees or shrubs of different species. Note the species you are using in the Metadata.

11. What do I do if there are not 5 trees or shrubs of the dominant species at my site? Should I measure any heights and circumferences?
If there are less than five, measure all the trees or shrubs at your site and make a note in the Metadata.

12. My school does not have a drying oven. Can we dry the grass another way?
First, check to see if you can use a drying oven at a community college, university, government agency or some other business or organization in your community. In warm, dry climates, graminoid biomass samples can be dried in mesh bags outside. Do not use a conventional oven to dry the graminoid vegetation. This is dangerous!

13. When I am measuring grass biomass, what do I do with mosses or lichens?
Moss and lichens are considered "Other Green" and have their own designation on the *Canopy and Ground Cover Data Sheet*. Do not include mosses or lichens in your dried samples. Record in metadata if these species comprise a large part of your green ground cover.

Manual Land Cover Mapping Protocol

Purpose

To produce a land cover type map of the 15 km x 15 km GLOBE Study Site from hard copies of Landsat satellite images

Overview

Students place clear transparencies over the Landsat TM images and use markers to outline and classify areas of different land cover using the MUC System. Students use their local expertise of their GLOBE Study Site and their Sample Site measurements to create and assess the accuracy of their maps.

Student Outcomes

Students learn how to interpret Landsat TM images and learn about the different types of land cover in their GLOBE Study Site. Students gain a spatial or landscape perspective of their local area.

Science Concepts

Geography

The characteristics and spatial distribution of ecosystems

Show how humans modify the environment

Scientific Inquiry Abilities

Classify land cover and create a land cover type map.

Evaluate the accuracy of land cover maps.

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate procedures, descriptions, and predictions.

Level

All

Time

Several class periods

Frequency

One time, but may be an iterative process as you progressively investigate more areas within your GLOBE Study Site

Materials and Tools

True-color, printed Landsat TM image of the 15 km x 15 km GLOBE Study Site

False-color, infrared printed Landsat TM image of the 15 km x 15 km GLOBE Study Site

Topographic maps of your area (if available)

Aerial photos of your area (if available)

MUC Field Guide or *MUC System Table* and *MUC Glossary of Terms*

Color photocopier (if available)

Clear plastic sheets or blank transparencies

Tape

Fine-point felt-tipped or transparency permanent markers

Manual Mapping: A Tutorial for the Beverly, MA Image

Getting to Know Your Difference/Error Matrix Field Guide

Preparation

Make color copies of the satellite images, if possible.

Make transparencies of a topographic map or other maps of the GLOBE Study Site (if possible, they should be the same scale as the satellite image.)

Review the MUC System.

Accuracy Assessment Tutorial

Prerequisites

Getting to Know Your Satellite Imagery and GLOBE Study Site

Odyssey of the Eyes Learning Activity

Read *Manual Mapping: A Tutorial for the Beverly, MA Image*

Familiarity with the MUC System

Bird Beak Accuracy Assessment Learning Activity

Manual Land Cover Mapping Protocol – Introduction

Look at the true color satellite image that your teacher has of your GLOBE Study Site. What different colors do you see? What do you think these colors mean? Compare the false color infrared image to the true color. Are the areas that are only one color in the true color image the same size and shape in the false color? What kind of land cover do you think the blue and black colors are? What kind of land cover do you think white or grays are? What is green in the true color image? Find a green area on the true color image; what color is that area in the false color image? What do the different shades of green in the true-color image represent? How is this land cover type represented in the false-color image? Repeat this with the other colors. Try to find your school in the image…it should look like a white or gray set of squares in the center of the image. Are there major roads in the image? What do they look like? Try to make a table (like the one below) that matches each of the different colors and their land cover types.

Work on your own or with a partner. Come up with a list of questions that you would like to answer about the satellite image of your area. From this list, or one that you generate as a class, pick one question that you will try to answer when you create a map from the satellite image. The question can have one or many parts.

The procedure GLOBE students use mimics what scientists do. Scientists ask questions about their images then use a computer version of manual mapping to answer them. This process is called *image interpretation*. *Image interpretation* is translating what you see on a printed image. The computer version of land cover mapping in GLOBE is the *Computer-aided Land Cover Mapping Protocol*. Scientists also use information that they have gathered in the field to label areas on the image. In GLOBE, this part of the data collection is known as the *Land Cover Sample Site Protocol*. Once you have collected many Land Cover Sample Sites, you can perform an accuracy assessment on your map to see how well you classified the land cover in your GLOBE Study Site. There is an *Accuracy Assessment Tutorial* in the *Appendix*, which will walk you through the steps.

The land cover maps made by GLOBE students can be used to help scientists' with their mapping efforts. Some GLOBE student maps can be used to help assess new satellite products (e.g., NASA's EOS satellites).

True-Color Image Color	False-Color Image Color	Type of Land Cover (I think)
Example: White	Example: White	Example: My School - Buildings

Teacher Support

The Measurement

Land cover type mapping is a subjective process where you and your students will have to use your knowledge of your GLOBE Study Site to interpret its image. Although this can be a daunting prospect at first, you will find that once you start looking at an image and identifying areas you know, it does become easier. You will be left to identify smaller and smaller areas as you continue the process. Just as scientists collect land cover data in the field in order to label their maps, you and your students should plan to visit sites that cannot be identified using your own knowledge, topographic maps and aerial photos. In those areas, you should carry out the *Land Cover Sample Site Protocol* and report the data to GLOBE. When you have completed the map, submit it to GLOBE.

The next step is to see how well your students classified the image by carrying out an accuracy assessment (by hand or on the GLOBE Web site) using additional *Land Cover Sample Site* data and the *Accuracy Assessment Tutorial*. From here, you can either work on improving the accuracy of your map or see how much change has occurred in your GLOBE Study Site by comparing your older image to a newer image. This comparison can be done using the *Change Detection Protocol*.

Teacher Follow-Up: Once all the areas on the image are identified, transfer the MUC identifications onto a master (paper) copy.

Follow directions in the *How to Submit Photos and Maps* section of the *Implementation Guide* to submit your maps to GLOBE.

Supporting Measurements

It may be necessary to carry out the *Land Cover Sample Site Protocol* at some sites where the MUC class is unknown. The *Biometry Protocol* measurements may be necessary at these sites.

Student Preparation

Students should spend time discussing what they see in the Landsat images. They should relate their observations to maps, aerial photos, and their own knowledge of the area.

Students must be familiar with the MUC system, and should discuss the type of land covers that are commonly found in their area.

Helpful Hints:

- Discuss and identify local examples of land cover types, review topographic maps, and discuss mapping and classification before beginning.
- You and your students do not have to label the entire GLOBE Study Site at once. Label areas as you become familiar with them. This may be carried out by other classes in subsequent years as well.
- This method is less accurate than others are because it is more subjective. Students must be careful and specific when outlining areas and assigning MUC classes.
- Have students begin by identifying the most obvious features - usually bodies of water and urban areas - and then progress to more difficult types, such as different types of natural vegetative cover.
- Sometimes cloud shadows resemble lakes and ponds. (See the Beverly, MA image for practice identifying clouds.)
- Use both the true color and false-color images since some types of land cover will be easier to distinguish in the false color and others will be easier to distinguish in the true-color.
- You will need to field-check areas where you cannot identify the type of land cover. Use the *Land Cover Sample Site Protocol.*
- You can also enlarge different parts of the printed image using a color photocopier or have it done at a local copy center. Have groups of students work on a small part of the image. Piece the image back together for final analysis. Once each group has mapped their section, combine the sections and compare results (especially along the edges) to identify problem areas. If groups of students differ in their labeling of a specific area, they must work out a method of reaching consensus.

- The Landsat image you use may be a few years old. Land cover may have changed since the image was acquired. What you identify on the Landsat TM image may be different than what you see in your ground assessments. In this case, students should work to determine what was on the ground at the time the satellite recorded the image data.
- If students cannot identify a specific area, have a class discussion to decide its MUC class.

In addition to the color of pixels in a Landsat image, there are a number of keys to help you interpret the land cover types in your image. These keys include shape, size, location, association, and texture. What keys you use depend on the features in your image. Below are some examples of how the keys can be used.

Shape: Agricultural areas tend to have abrupt linear edges and geometric shapes like rectangles and squares. Streams are linear features that can have many bends and curves. Roads frequently have fewer curves than streams.

Size: Major highways and rivers can be distinguished from smaller roads and tributaries.

Topographic or geographic location: If you are in a location with mountains and valleys, forested areas will tend to be on the mountainous areas with steeper slopes, while grassland and agricultural areas will be within the valleys. Since Landsat images are acquired in the morning, hillsides opposite the Sun may be in shadow.

Association: A vegetated area within an urban setting may be a park or cemetery. Wetlands may be located next to rivers, lakes or estuaries. Commercial centers will be located next to major roads, railroads, or waterways.

Texture: In a false-color image, commercial areas often will be consistently light blue or white. Residential areas, however, may have a speckled appearance of light blue/white and red. The light blue/white indicates buildings and pavement, and the red indicates the grass and trees that may line the streets and surround individual dwellings.

Questions for Further Investigation

What is the dominant land cover type in your area?

How many different land cover types are there in your GLOBE Study Site?

What land cover types look similar? Why?

How do the land cover types in your area affect the air temperature near the surface of the ground? Where in your GLOBE Study Site would you find cooler air temperatures on a warm, sunny day?

Do you expect much surface run-off from precipitation in the dominant land cover types in your area? Why?

If you had never visited your area but had a Landsat image, what aspects of the local environment would you perceive correctly and what would you not be able to perceive?

What could you do to improve your overall accuracy?

How accurate is your map if someone wanted to find a good place to have a picnic in the woods?

How accurate is your map if you wanted to see how many times you correctly identified a park or playing field?

How could next year's class use your data to create a better student classified map?

If you live in coastal or estuarine areas, how would the position of the tides (high or low) affect your land cover mapping?

How would the time of year your satellite image was acquired affect land cover mapping in your part of the world?

What other conditions at the time your image was acquired might influence your land cover mapping?

How do land cover and soil relate across your GLOBE Study Site?

Manual Land Cover Mapping Protocol
Field Guide

Task

Create a land cover type map by identifying the areas of different land cover in hard copies of your true-color and false-color infrared Landsat TM satellite images.

What You Need

- ❑ *Manual Mapping: A Tutorial for the Beverly, MA Image*
- ❑ True-color and False-color Infrared prints of Landsat TM image of the 15 km x 15 km GLOBE Study Site or color copies of the GLOBE Study Site
- ❑ Blank transparencies or plastic sheets
- ❑ Tape
- ❑ Local topographic maps or transparencies of local topographic maps
- ❑ Fine point felt-tipped permanent markers
- ❑ *MUC Field Guide* or *MUC System Table* and *MUC Glossary of Terms*

What To Do

1. Tape a blank transparency sheet over the false-color infrared satellite image.
2. Mark the corners of the satellite image and label the top of the image on your blank transparency. If it moves, you can put it back where it belongs using these marked corners. This will also allow you to move the transparency to the true-color image.
3. Outline areas of similar land cover using the markers. If you have enough colors, use a different color to represent each area that you feel is a distinctive land cover type.
4. Assign each area a MUC class from the *MUC Field Guide* or *MUC System Table* and *MUC Glossary of Terms*, using your knowledge of the area.
5. If you cannot label an area, discuss the best possible choice of land cover type with your classmates or ask a person in your class who lives near the area to visit it on their way to or from school.
6. If there are any areas left to identify, visit the site and perform the *Land Cover Sample Site Protocol.*
7. Label the map completely. It may help to place the transparency on a blank, white sheet of paper to check for unlabeled areas.
8. See your teacher for instructions on how to submit your map to GLOBE.

Some hints to help with false-color infrared TM images:

- Red represents actively growing green vegetation (pink areas often represent grasslands, bright red represents hardwoods and fields, dark red represents evergreens).
- Black represents water or a cloud shadow.
- Blue–white represents urban areas, exposed rock, sand, and bare soils.

Frequently Asked Questions

1. What if I cannot identify a vegetated land cover type from the image to all four levels of MUC?

If you cannot identify the entire MUC class for an area, you will need to visit this area and use the *Land Cover Sample Site Protocol* and any necessary biometry measurements to complete the MUC identification.

2. What if two groups disagree on the MUC value of an area in our image?

If groups cannot agree on the MUC value of an area, you will need to carry out the *Land Cover Sample Site Protocol* and any biometry measurements necessary to settle the disagreement, unless you know someone who lives nearby who can validate the ground cover there.

3. What do we do if there is an area in our image for which nobody knows the MUC value?

Again, the only way to know for certain is to visit the site and collect field data.

4. We have a water body that is not black, but green, or even brown. What does this mean?

In both true color and false-color infrared images, water is normally black. An exception is the very clear water found in parts of the Caribbean. If your water appears brown, green or grey, it usually indicates that there is some material on the surface of the water. This may be plant growth, or suspended sediment that is being transported by the water.

Manual Mapping Protocol –Looking at the Data

Are the data reasonable?

After creating a land cover map from your Landsat image, you should determine whether the types of land cover that you identified are reasonable and accurate for the area that you live in. For instance, if you are located in a mid-latitude temperate climate, does your map include land cover types only found in the equatorial tropical zone? Does it make sense to have land cover types only found in extremely dry desert-like areas? Do you have classes for mountainous areas when you are located in a coastal lowland? Ask yourself questions like these about your own land cover type map. Check the MUC classes and definitions to determine whether the land cover classes in your map make sense for your GLOBE Study Site.

Next, look at where each of these land cover types are located on your map. Using your knowledge of the area and other sources of information like a print-out of your Landsat image, topographic maps and aerial photos (if available), do the locations of the land cover types make sense? If not, which land cover types do not make sense?

After looking at your map and seeing whether it is reasonable, you are now ready to perform a quantitative accuracy assessment. The *Accuracy Assessment Tutorial* (found in the *Appendix)* provides an example showing how to organize your data and perform the accuracy assessment.

What do scientists look for in these data?

Remote sensing scientists do not have one acceptable overall accuracy percentage to guide them when making a map from satellite imagery. Required accuracy levels depend on the objective of the map. It is very interesting to study the error matrix and observe what land cover classes are being confused with each other. All errors are not equal. In most cases, it would be far worse to label an area as water when it is conifer forest than it would be to label a conifer woodland as a conifer forest. In addition, remote sensing scientists try to improve their maps using the information gained in the error matrix. These attempts may involve collecting more land cover data to assist in the mapping, studying the spectral response patterns of land cover types, and/or applying different classification techniques. Land cover mapping from satellite imagery is often an iterative process and accuracy assessment can take place many times before a final map is achieved. Once scientists have an assessed map, they use it to answer the questions they set out to answer. They may compare the amounts and locations of natural and developed areas, the percentages of land cover types that are important to the community such as agriculture, wetlands, transportation, recreation areas, etc. or specific locations of habitats they are studying.

An Example of Student Inquiry

A group of 12 students living in Washington, DC, United States set out to create a land cover map of their area. They looked at the Landsat image of their GLOBE Study Site and decided that the map would get finished faster if they divided the Landsat image into four parts. The 12 students formed four groups of three students each. Each group was responsible for labeling all the different land cover types for the section of the image assigned to them. After completing the sections, the four parts would be put back together to create one map of the entire GLOBE Study Site.

Their teacher used MultiSpec (GLOBE-provided imaging software) to divide the image into four parts and used a color printer to print each part on a separate sheet of paper. She decided to enlarge the image this way because she was familiar with the software and had access to a color printer. Otherwise she would have enlarged the image using a color copier.

Figure LAND-MA-1: GLOBE Study Site Subset of Washington, DC

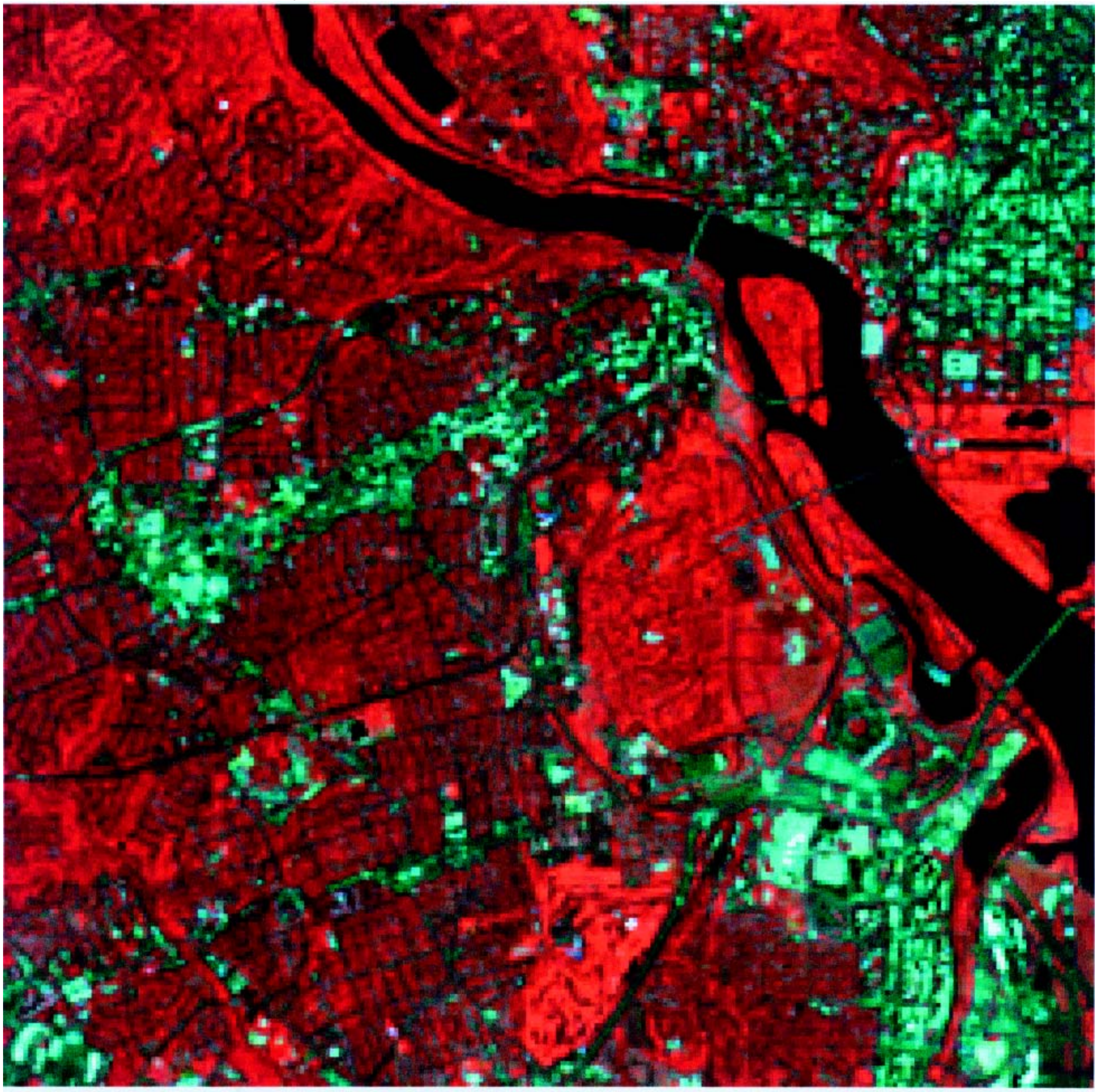
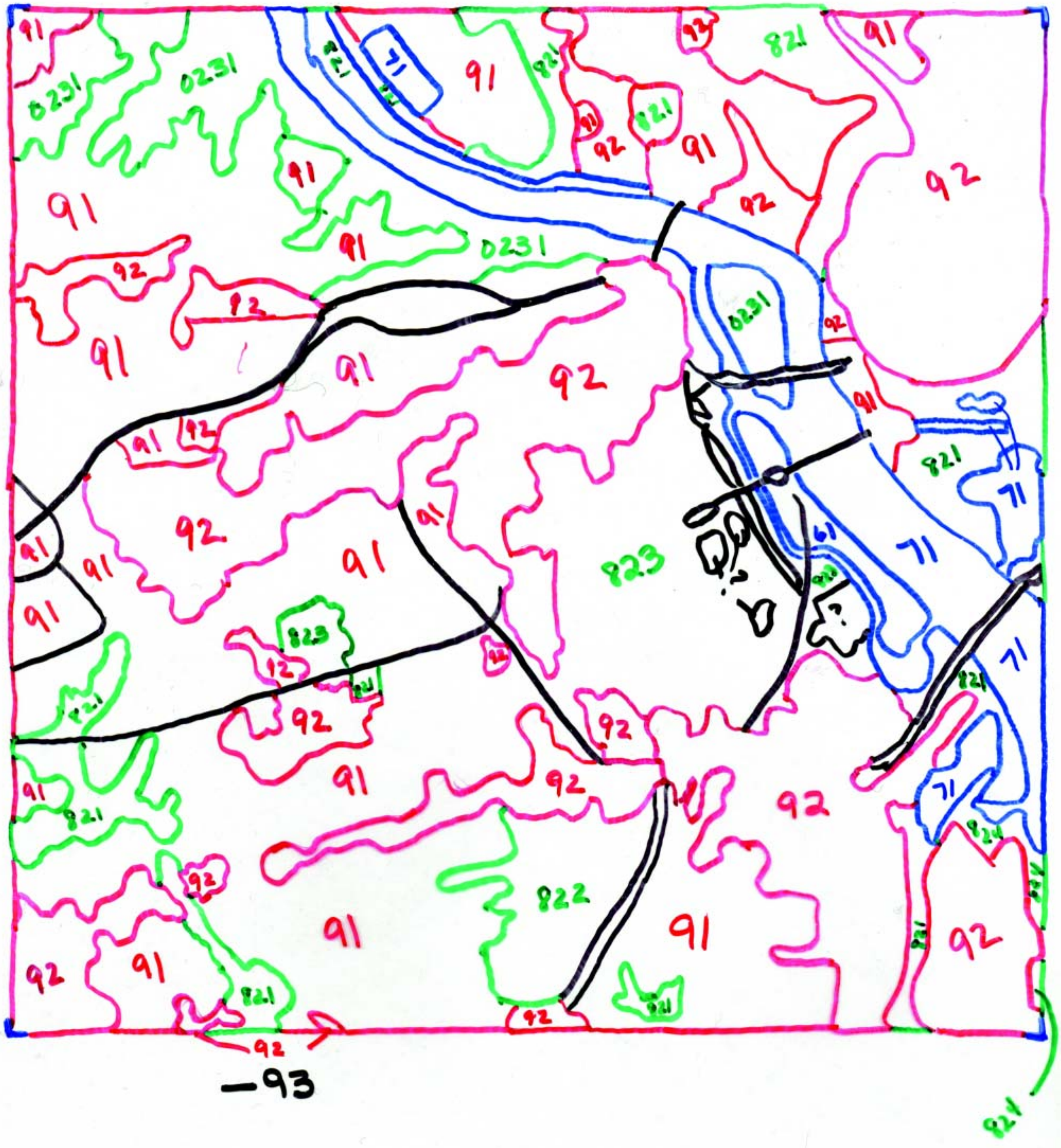


Figure LAND-MA-2: Manual Map of GLOBE Study Site Subset



Group A had the southwest quadrant of their GLOBE Study Site. After reviewing *Manual Mapping: A Tutorial for the Beverly, MA, Image*, the students in Group A examined the image of their section. Two of the students identified where they lived. The other student lived in a different part of the city. The students used a topographic map and a tourist map to help identify the MUC classes of the different land cover types. Using color felt-tip pens, they outlined different areas of similar color. They had pens of four different colors so they assigned a color for each MUC class group. For instance, red was used for some urban classes (MUC 91 and 92). Black was used for transportation (MUC 93). Blue was used for water (MUC 7). However, they did not have enough different colors for all the MUC classes, so they decided to use green for the different vegetated areas.

While making the map, one student commented that the residential areas had a "patchy" look, meaning that those areas were not all one color. Blue and red pixels were intermixed on the false-color image. He wasn't sure whether he should outline each pixel or small group of pixels individually or lump the blue and red mixture together. He noticed that this texture was fairly consistent and that groups of pixels with similar red or blue colors were less than 3 x 3 pixel squares. He lived in one of the residential areas and thought that the blue indicated roads, driveways and houses and that red indicated the vegetation in yards and along streets. Because the pixel groups were small and residential areas have a mixture of vegetation and built things, he suggested grouping the mixture as one land cover type, MUC 91 (Residential). Another student commented that the image contained many roads of different sizes. After discussing, the group decided to only identify roads that were large and could be clearly seen and separated from other land cover types like MUC 91 (Residential) and 92 (Commercial and Industrial). They labeled the roads fitting these criteria as MUC 93 (Transportation).

They were very proud of their completed map and were eager to then see how accurate their map was. After reading the *Accuracy Assessment Tutorial*, they selected 10 sites to visit and perform the *Land Cover Sample Site Protocol*. They chose a Saturday when all three of them were available for the data collection. One of their parents agreed to drive them around. They borrowed a GPS receiver, and gathered a camera, film, compass, *Data Sheets* and *Field Guides*. They went to the sites and collected data. One student entered the data on the GLOBE Web site.

Following the instructions of the *Accuracy Assessment Tutorial*, they created a table comparing their map classifications and the validation data from the Sample Sites. See Figure LAND-MA-3.

After creating the table, they made a difference/error matrix (Figure LAND-MA-4). They calculated an overall accuracy of 80%. They felt pleased with what they did and were curious how well the other groups did and what the overall accuracy of the map of the entire GLOBE Study Site would be after all the groups combine their sections together.

Figure LAND-MA-3: Student Inquiry Completed Accuracy Assessment Work Sheet

Completed Accuracy Assessment Work Sheet

Site Name	Student Map Classification Data from GLOBE Study Site	Validation Data from Land Cover Sample Site	✔	✘
1. Potomac River by 14th Street bridge	71	71	✔	
2. Grass by airport	821	824		✘
3. Gary's neighborhood	91	91	✔	
4. Courthouse Metro shops	92	92	✔	
5. Phil's neighborhood	91	91	✔	
6. Potomac Park	0222	0231		✘
7. Park near hospital	821	821	✔	
8. Arlington Cemetery	823	823	✔	
9. Roosevelt Island	0231	0231	✔	
10. Georgetown area	92	92	✔	

MUC Class List

0222 – Closed Forest, Mainly Deciduous, Cold-Deciduous with Evergreens, With Evergreen Needle-Leaved Trees

0231 – Closed Forest, Mainly Deciduous, Cold-Deciduous without Evergreen Trees, Temperate Lowland and Submontane Broad-Leaved

71 - Open Water, Freshwater

821 – Cultivated Land, Non-Agriculture, Parks and Athletic Fields

823 – Cultivated Land, Non-Agriculture, Cemeteries

824 – Cultivated Land, Non-Agriculture, Other Non-Agriculture

91 - Urban, Residential

92 – Urban, Commercial and Industrial

93 – Urban, Transportation

Figure LAND-MA-4: Student Inquiry Difference/Error Matrix

Difference/Error Matrix

	MUC 71	MUC 821	MUC 91	MUC 92	MUC 0222	MUC 823	MUC 824	MUC 0231	**Row Totals**
MUC 71	|								**1**
MUC 821		|					|		**2**
MUC 91			||						**2**
MUC 92				||					**2**
MUC 0222								|	**1**
MUC 823						|			**1**
MUC 824									**0**
MUC 0231								|	**1**
Column Totals	**1**	**1**	**2**	**2**	**0**	**1**	**1**	**2**	**10**

Overall Accuracy: 8 ÷ 10 x 100 = 80%

Computer-aided Land Cover Mapping Protocol

Purpose

Students produce a land cover type map of the 15 km x 15 km GLOBE Study Site from the digital file of their Landsat satellite image using MultiSpec software.

Overview

Students use MultiSpec software to group pixels with similar spectral patterns in the Landsat TM data set. Students classify the land cover type of each spectral group using the MUC System. Students use their local expertise of their GLOBE Study Site and their sample site measurements to assess the accuracy of their maps.

Student Outcomes

Students gain experience in the use of remotely sensed image data. They gain an understanding of the need for complementary *in situ* data collection. Students create a map and gain a spatial or landscape perspective of their local area.

Science Concepts

Geography

The characteristics and spatial distribution of ecosystems

Show how humans modify the environment.

Scientific Inquiry Abilities

Classify land cover and create a land cover type map.

Evaluate how accurate the land cover map type is using accuracy assessment.

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate procedures, descriptions, and predictions.

Level

Intermediate and Advanced

Time

Several class periods

Frequency

One time, but may be an iterative process as you progressively investigate more areas within the GLOBE Study Site.

Materials and Tools

Computer

MultiSpec computer software (provided by GLOBE or downloaded from the Web)

512 x 512 pixel Landsat TM image data of the 15 km x 15 km GLOBE Study Site (disk provided by GLOBE)

MUC Field Guide or *MUC System Table* and *MUC Glossary of Terms*

Topographic maps of your area (if available)

Aerial photos of your local area (if available)

Introduction to the MultiSpec Program and the *Computer-aided Mapping Tutorial* (from the MultiSpec CD)

Printed Landsat TM images of the 15 km x 15 km GLOBE Study Site

Getting to Know Your Difference/Error Matrix Field Guide

Preparation

Install the MultiSpec software on the computers students will be using

Install the image on the computers the students will be using

Familiarize yourself with MultiSpec and the *Computer-aided Mapping Tutorial* (from the MultiSpec CD)

Review the MUC System

Accuracy Assessment Tutorial

Prerequisites

Odyssey of the Eyes Learning Activity

Review and practice the *Introduction to the MultiSpec Program* and the *Computer-aided Mapping Tutorial* (from the MultiSpec CD)

Ability to use the *MUC Field Guide* or *MUC System Table* and *MUC Glossary of Terms*

Bird Beak Accuracy Assessment Learning Activity

Computer-aided Land Cover Mapping Protocol – Introduction

Look at the true color satellite image that your teacher has of your GLOBE Study Site. What different colors do you see? What do you think these colors mean? Compare the false color infrared image to the true color. Are the areas that are only one color in the true color image the same size and shape in the false color? What kind of land cover do you think the blue and black colors are? What kind of land cover do you think white or grays are? What is green in the true color image? Find a green area on the true color image; what color is that area in the false color image? What do the different shades of green in the true-color image represent? How is this land cover type represented in the false-color image? Repeat this with the other colors. Try to find your school in the image…it should look like a white or gray set of squares in the center of the image. Are there major roads in the image? What do they look like? Try to make a table (like the one below) that matches each of the different colors and their land cover types.

Work on your own or with a partner. Come up with a list of questions that you would like to answer about the satellite image of your area. From this list, or one that you generate as a class, pick one question that you will try to answer when you create a map from the satellite image. The question can have one or many parts.

Many maps are made from *remotely sensed data*. *Remotely sensed data* is data that is collected from far away using your senses. The protocol GLOBE students use mimics what scientists do. Scientists who make maps from satellite imagery ask questions about their images and use software similar to MultiSpec to answer them. This process uses standard statistical methods to identify map groups, called clusters. *Clusters* are groups of spectrally similar pixels that the computer identifies and groups together according to their patterns of reflectance. The computer gives each cluster a random color. Students must classify the land cover type of each cluster using the MUC System. Some types can be labeled from just student knowledge of the area while other types can be labeled using topographic maps, aerial photographs, etc. and data collected using the *Land Cover sample site Protocol*. Scientists also use knowledge that they have learned in the field or from other collected data to label the clusters the computer makes. Once you have collected many Land Cover Sample Sites, you can perform an accuracy assessment on your map to see how well you classified the land cover in your GLOBE Study Site. There is an *Accuracy Assessment Tutorial* in the *Appendix*, which will walk you through the steps.

The land cover maps made by GLOBE students can be used to help scientists' with their mapping efforts. Some GLOBE student maps can be used to help assess new satellite products (e.g., NASA's EOS satellites).

True-Color Image Color	False-Color Image Color	Type of Land Cover (I think)
Example: White	Example: White	Example: My School - Buildings

Teacher Support

The Measurement

Land cover type mapping is a subjective labeling process. Using your knowledge of your GLOBE Study Site, you and your students will interpret the land cover types represented by the pixels of your satellite image. In the *Manual Land Cover Mapping Protocol,* you complete this process completely by hand. Alternatively, a computer can aid in the process of clustering pixels within the image as described in this protocol. The computer performs the initial clustering of pixels but you will need to interpret the land cover types that these clusters represent. Although this can be a daunting prospect at first, you will find that once you start looking at an image and identifying clusters you know, it does become easier. You will be left to identify fewer and fewer clusters as you continue the process. Just as scientists collect land cover data in the field in order to label their clusters, you and your students should plan to visit sites that cannot be identified using your knowledge, spectral signatures, topographic maps and aerial photos. In those areas, you should carry out the *Land Cover Sample Site Protocol* and report the data to GLOBE. Once your students are proficient with MUC, they can also visit the unknown sites to identify the land cover type on their own. In this case, the site would not be reported to GLOBE but you can use it to label the land cover type map you are creating. When you have completed the map, submit it to GLOBE.

The next step is to see how well your students labeled the image by carrying out an accuracy assessment (by hand or on the GLOBE Web site) using additional Land Cover Sample Site data and the *Accuracy Assessment Tutorial*. From here, you can either work on improving the accuracy of your map or see how much change has occurred in your GLOBE Study Site by comparing a 1990's image to a 2000's image. This comparison can be done using the *Change Detection Protocol.*

Teacher Follow-Up: Save the "best" classified clustered image. Use the File menu to save it onto a disk as a TIFF file. If you have a color printer, print copies of your students' land cover map(s). Report your data to the GLOBE Student Data Archive by e-mailing a file containing the TIFF or by mailing a copy of the TIFF to GLOBE following the directions in the *How to Submit Photos and Maps* section of the *Implementation Guide*.

Supporting Measurements

It may be necessary to carry out the *Land Cover Sample Site Protocol* at some sites where the MUC is unknown. The *Biometry Protocol* measurements may be necessary at these sites.

Student Preparation

Students should spend time discussing what they see in the Landsat images. They should relate their observations to maps, aerial photos, and their own knowledge of the area.

Students must be familiar with the MUC system, and should discuss the type of land covers that are commonly found in their area.

Helpful Hints

- Discuss and identify local examples of land cover types, review topographic maps, and discuss classification before beginning this protocol.
- The Multispec default value of ten clusters is recommended to start with. If this does not appear to adequately represent the land cover types in your image, you may want to increase the number of clusters.
- Remember that this process is iterative. You do not have to label everything at once. Nor will everything be correct. You will improve your map as you get more familiar with your area and take needed ground measurements.
- Have students begin by identifying the most obvious features - usually bodies of water and urban areas - and then progress to more difficult types, such as different types of natural vegetative cover.
- Sometimes cloud shadows resemble lakes and ponds. (See the Beverly, MA image for practice identifying clouds.)

- Use both the true-color and false-color images since some types of land cover will be easier to distinguish in the false-color and others will be easier to distinguish in the true-color.
- Have your students fill in the name of your image on their *Field Guide* before they begin.
- If your students completed the *Manual Land Cover Mapping Protocol,* use the same numbers of classes they found in their Student Classified Map or 10 clusters, whichever is greater.
- Hardwood forests may look spectrally similar to actively growing fields.
- The remote sensing image you use may be a few years old. Land cover may have changed since the image was acquired. What you identify on the Landsat TM image may be different than what you see in your ground assessments. In this case, students should work to determine what was on the ground at the time the satellite recorded the image data.
- You will need to field-check areas where you cannot identify the type of land cover. Use the *Land Cover Sample Site Protocol.*

In addition to the color of pixels in a Landsat image, there are a number of keys to help you interpret the land cover types in your image. These keys include shape, size, location, association, and texture. What keys you use depend on the features in your image. Below are some examples of how the keys can be used.

Shape: Agricultural areas tend to have abrupt linear edges and geometric shapes like rectangles and squares. Streams are linear features that can have many bends and curves. Roads frequently have fewer curves than streams.

Size: Major highways and rivers can be distinguished from smaller roads and tributaries.

Topographic or geographic location: If you are in a location with mountains and valleys, forested areas will tend to be on the mountainous areas with steeper slopes, while grassland and agricultural areas will be within the valleys. Since Landsat images are acquired in the morning, hillsides opposite the Sun may be in shadow.

Association: A vegetated area within an urban setting may be a park or cemetery. Wetlands may be located next to rivers, lakes or estuaries. Commercial centers will be located next to major roads, railroads, or waterways.

Texture: In a false-color image (4-3-2 band combination), commercial areas often will be consistently light blue or white. Residential areas, however, may have a speckled appearance of light blue/white and red. The light blue/white indicates buildings and pavement, and the red indicates the grass and trees that may line the streets and surround individual dwellings.

Questions for Further Investigation

Are there distinct land cover classes that this computer-aided mapping process did not “resolve,” or separate?

Did the process artificially separate a land cover type into different clusters?

Does increasing the number of clusters (try several different numbers) improve the computer’s ability to resolve these land cover types?

If you had never visited your area but had a Landsat image, what aspects of the local environment would you perceive correctly and what would you not be able to perceive?

What could you do to improve your overall accuracy?

How accurate is your map if someone wanted to find a good place to have a picnic in the woods?

How accurate is your map if you wanted to see how many times you correctly identified a park or playing field?

Which was better, your producer’s or user’s accuracy? Why do you think that is?

How could next year’s class use your data to create a better student classified map?

Computer-aided Land Cover Mapping Protocol
Field Guide

Task
Create a land cover type map using MultiSpec software to cluster the spectrally similar pixels of the digital file of your Landsat TM satellite image. Label each cluster according to the land cover type you feel is represented based on your knowledge of the area.

What You Need
- ❑ *Introduction to the MultiSpec Program* and *Computer-aided Mapping Tutorial* (*from the MultiSpec CD*)
- ❑ Computer capable of running MultiSpec computer software
- ❑ MultiSpec computer software
- ❑ 512 x 512 pixel Landsat TM image data of the 15 km x 15 km GLOBE Study Site
- ❑ *MUC Field Guide* or *MUC System Table* and *MUC Glossary of Terms*

What To Do
1. Start the MultiSpec program on the computer.
2. Open the file containing the Landsat TM image of your GLOBE Study Site. It is labeled

   ____.
3. Create a new project and select *Cluster* from the **Processor** menu.
4. Select the appropriate number of clusters according to the number of groups you wish to classify. The first time you should use the default of 10 clusters, unless your teacher says otherwise. Provide the system with other information as directed in the *Introduction to the MultiSpec Program* and the *Computer-aided Mapping Tutorial* (from the MultiSpec CD).
5. Once the image has been clustered, examine the area included in each cluster.
6. Assign a land cover class to each cluster.
   a. If you know the land cover type of an area, assign a land cover class from the MUC System to the cluster.
   b. If you do not know the land cover of an area, use the data from a Land Cover Sample Site within the area to assign the land cover class from the MUC System.
      - If there are no land cover sites within the area of a cluster, perform the *Land Cover Sample Site Protocol* for a site within this area.
      - If there are multiple sites within an area, use only one of these sites to make the land cover class assignment and reserve the others for performing an accuracy assessment.
7. Rename each cluster to correspond with its appropriate MUC class.
8. Save the classified clustered image. Use the **File** menu to save it onto a disk as a TIFF file.
9. See your teacher for instructions of how to report your data to GLOBE.

Frequently Asked Questions

1. How many clusters should I use?

For your first attempt at clustering, use the MultiSpec default of 10 clusters.

2. I have used MultiSpec to create 10 clusters. In one of the clusters I know that there are 2 different types of MUC classes. What do I do?

In this case, you should repeat the clustering with additional clusters, for example, this time, use 12. It is also possible that the spectral patterns of the two land cover types are close enough that the software cannot distinguish them.

3. I cannot differentiate roads from commercial areas. What should I do?

Developed areas, MUC 9, are the most difficult to separate in a satellite image. All are composed of minerals and have very similar reflectance patterns. It may not be possible to separate them in a clustering. Sometimes, you can create a separate sub-image of just the urban area and cluster that alone in order to differentiate the different urban types. Do not attempt this unless you are an experienced MultiSpec user.

4. What if I cannot identify a vegetated land cover type from the image to all four levels of MUC?

If you cannot identify the entire MUC class for an area, you will need to visit this area and use the *Land Cover Sample Site Protocol* and any necessary biometry measurements to complete the MUC identification.

5. What if two groups disagree on the MUC value of an area in our image?

If groups cannot agree on the MUC value of an area, you will need to carry out the *Land Cover Sample Site Protocol* and any biometry measurements necessary to settle the disagreement, unless you know someone who lives nearby who can validate the ground cover there.

6. What do we do if there is an area in our image for which nobody knows the MUC value?

The only way to know for certain is to visit the site and collect field data.

7. We have a water body that is not black, but green, or even brown. What does this mean?

In both true color and false-color infrared images, water is normally black. An exception is the very clear water found in parts of the Caribbean. If your water appears brown, green or grey, it usually indicates that there is some material on the surface of the water. This may be plant growth, or suspended sediment that is being transported by the water.

Computer-aided Land Cover Mapping– Looking at the Data

Are the data reasonable?

After creating a land cover map from your Landsat image, you should determine whether the types of land cover are reasonable and accurate. For instance, if you are located in a mid-latitude temperate climate, does your map include land cover types only found in the equatorial tropical zone? Does it make sense to have land cover types only found in extremely dry desert-like areas? Do you have classes for mountainous areas when you are located in a coastal lowland? Ask yourself questions like these about your own land cover type map. Check the MUC classes and definitions to determine whether the land cover classes in your map make sense for your GLOBE Study Site.

Next, look at where each of these land cover types are located on your map. Using your knowledge of the area and other sources of information like a print-out of your Landsat image, topographic maps and aerial photos (if available), do the locations of the land cover types make sense? If not, which land cover types do not make sense?

After looking at your map and seeing whether it is reasonable, you are now ready to perform a quantitative accuracy assessment. The *Accuracy Assessment Tutorial* provides an example showing how to organize your data and perform the accuracy assessment.

What do scientists look for in these data?

Remote sensing scientists do not have one acceptable overall accuracy percentage to guide them when making a map from satellite imagery. Required accuracy levels depend on the objective of the map. It is very interesting to study the error matrix and observe what land cover classes are being confused with each other. All errors are not equal. In most cases, it would be far worse to label an area as water when it is conifer forest than it would be to label a conifer woodland as a conifer forest. In addition, remote sensing scientists try to improve their maps using the information gained in the error matrix. These attempts may involve collecting more land cover data to assist in the classification, studying the spectral response patterns of land cover types, and/or applying different classification techniques. Land cover mapping from satellite imagery is often an iterative process and accuracy assessment can take place many times before a final map is achieved. Once scientists have an assessed map, they use it to answer the questions they set out to answer. They may compare the amounts and locations of natural and developed areas, the percentages of land cover types that are important to the community such as agriculture, wetlands, transportation, recreation areas, etc. or specific locations of habitats they are studying.

An Example of Student Inquiry

A group of students in Kyiv, Ukraine were working on creating a land cover map for their GLOBE Study Site. Using MultiSpec, they created an image with 10 clusters. They labeled 8 of the clusters using their knowledge of the types of land cover around their homes and school, and a topographic map of the area. They were uncertain what the MUC classes were for two of the clusters. So they picked out a site for each cluster on the Landsat image. Different students went to each of these sites and performed the *Land Cover Sample Site Protocol*. One site had a MUC code of 811 (Cultivated Land, Agriculture, Row Crop and Pasture). The other site had a MUC code of 92 (Urban, Commercial and Industrial). They used these MUC classes to label the 2 unknown clusters in their image and assumed that all other pixels in these 2 clusters were of the same land cover types.

The students examined the land cover map they created. They discussed how the map looked. They felt fairly confident that the water, closed forest and woodland areas were classified correctly, but questioned whether some of the urban and cultivated areas were correct. Specifically they thought that:

1. roads were included in other MUC 9 classes,
2. bare agricultural fields and commercial areas were not separated into different clusters very well,
3. green agricultural fields and non-agricultural areas were not separated into different clusters well.

They decided to see if their hunches were correct.

Figure LAND-UC-1: Kyiv, Ukraine 15 km x 15 km GLOBE Study Site

Figure LAND-UC-2: Unsupervised Clustered Land Cover Map of Kyiv, Ukraine with Two Unlabeled Classes

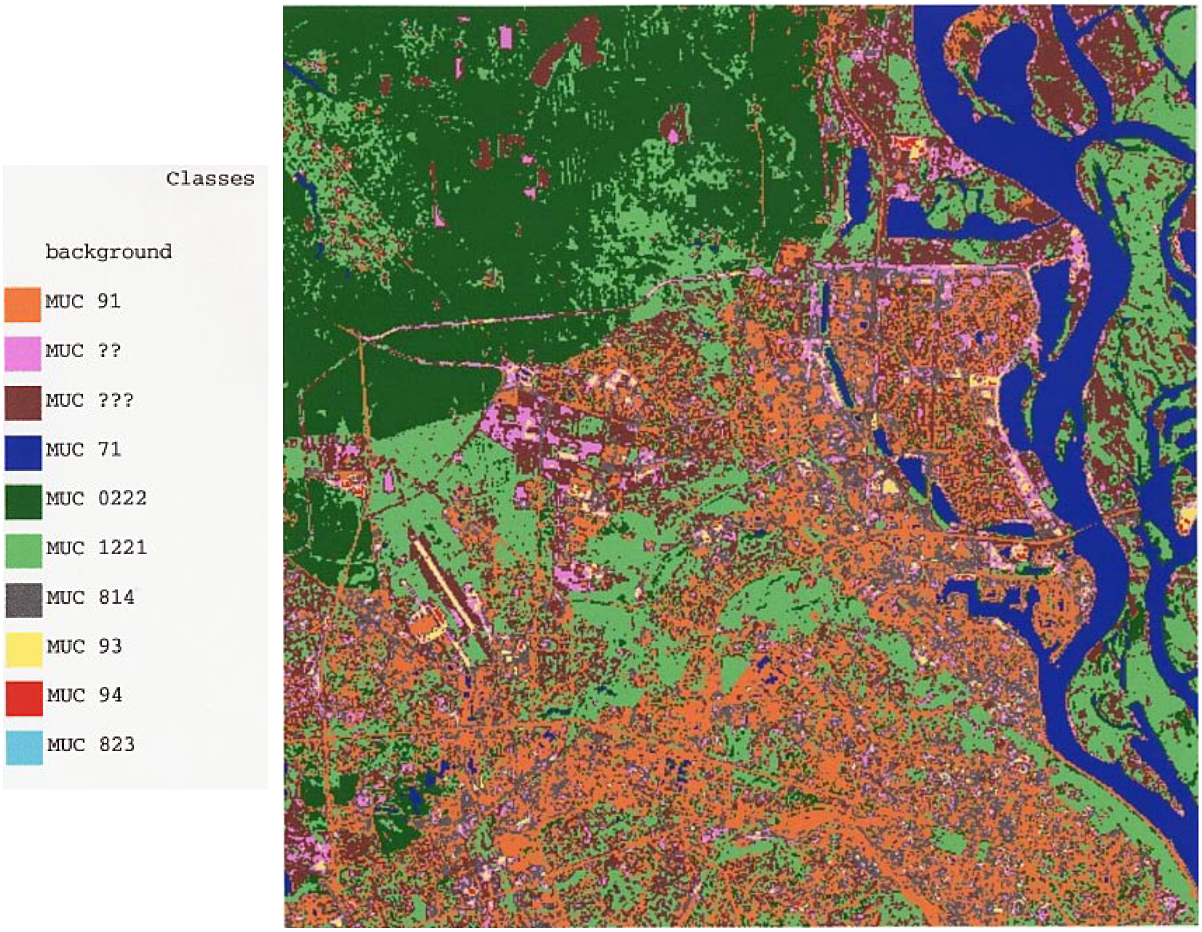
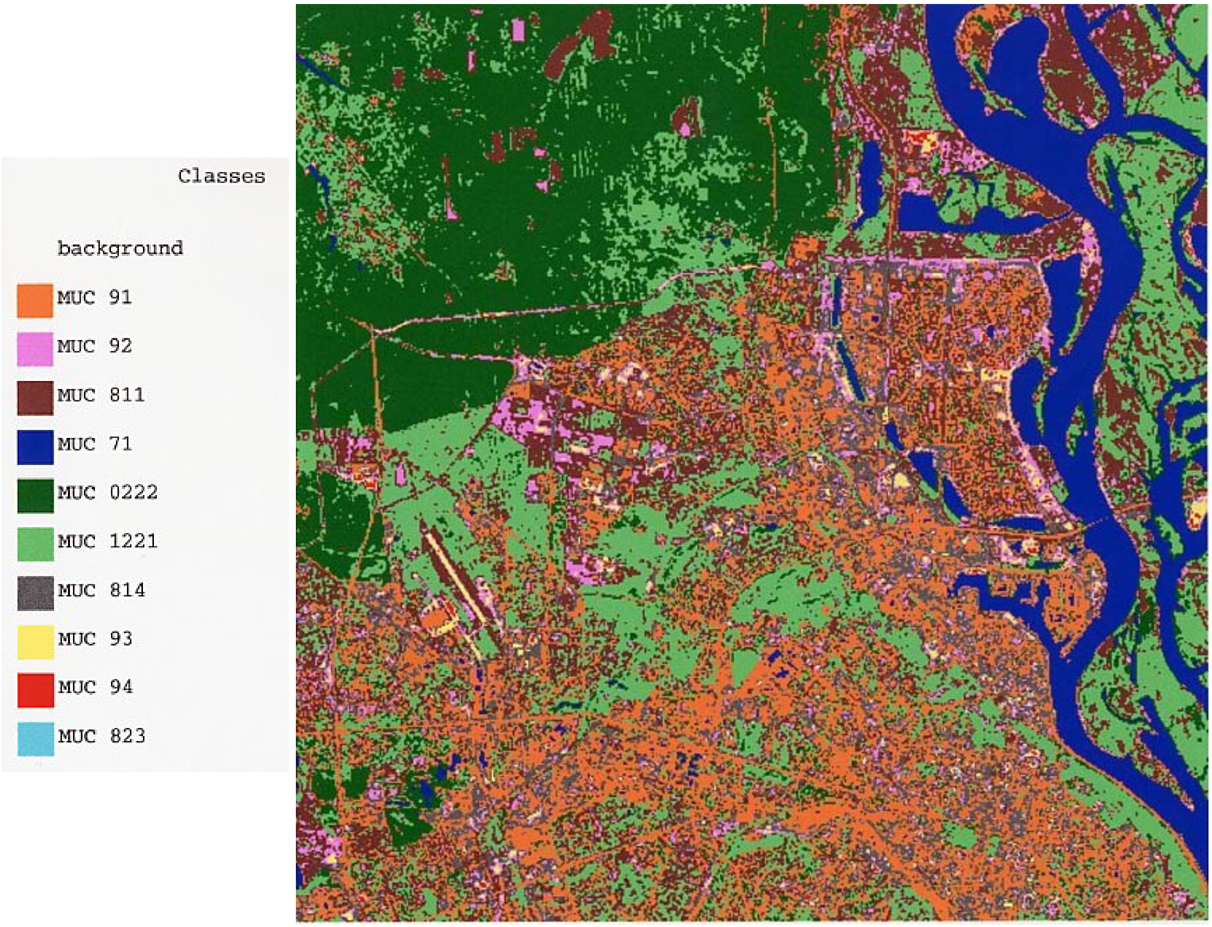


Figure LAND-UC-3: Completed Land Cover Type Map of Kyiv, Ukraine



Earlier in the school year, the group and other classmates collected a number of *Land Cover Sample Site* data. In addition, the class last year collected data for another three sites. Using these data, they first created a table comparing their classifications of the clustered image and the validation data from the Sample Sites (See Table below). They remembered NOT to include the 2 sites they used to identify their unknown clusters. They had a total of 15 validation sites.

Completed *Accuracy Assessment Work Sheet*

	Site Name	Student Map Classification Data from GLOBE Study Site	Validation Data from Land Cover Sample Sites	✔	✗
1	River	71	71	✔	
2	Grass by airport	811	824		✗
3	John's Farm	811	811	✔	
4	Downtown Central Square	92	92	✔	
5	Big Woods by Lorenzo's House	0222	0222	✔	
6	Grassland Across River	811	4223		✗
7	LeRoy's Neighborhood	91	91	✔	
8	Highway 66	93	92		✗
9	Natalie's Property	811	824	✔	
10	Airport	93	93	✔	
11	George's Fallow Field	92	811		✗
12	Leonid's Grandma's Neighborhood	92	91		✗
13	Woodland near Janice's House	1222	1222	✔	
14	Forest next to Grandma's House	0222	0222	✔	
15	Mary's Market	91	92		✗

MUC Class List

0222 – Closed Forest, Mainly Deciduous, Cold-Deciduous with Evergreens, With Evergreen Needle-Leaved Trees
1222 – Woodland, Mainly Deciduous, Cold-Deciduous with Evergreens, With Evergreen Needle-Leaved Trees
4223 – Herbaceous Vegetation, Medium Tall Graminoid, With Trees Covering <10%, Trees: Broad-Leaved Deciduous
71 – Open Water, Freshwater
811 – Cultivated Land, Agriculture, Row Crop and Pasture
824 – Cultivated Land, Non-Agriculture, Other Non-Agriculture
91 - Urban, Residential
92 – Urban, Commercial and Industrial
93 – Urban, Transportation
94 – Urban, Other

After creating the table, they made a difference/error matrix.

Validation Data

Student Map Classification	MUC 71	MUC 811	MUC 92	MUC 0222	MUC 1222	MUC 91	MUC 93	MUC 824	MUC 4223	Row Totals
MUC 71	I									**1**
MUC 811		I						II	I	**4**
MUC 92		I	I			I				**3**
MUC 0222				II						**2**
MUC 1222					I					**1**
MUC 91			I			I				**2**
MUC 93			I				I			**2**
MUC 824										**0**
MUC 4223										**0**
Column Totals	**1**	**2**	**3**	**2**	**1**	**2**	**1**	**2**	**1**	**15**

They calculated an overall accuracy of 53%. When they calculated the user's and producer's accuracies, they noticed that the MUC classes for open water, forest and woodland areas were classified correctly, but that many of the developed sites were not. They thought that the data supported their hunches.

Accuracy Assessment Percentages

Overall Accuracy

$8 \div 15 \times 100 = 53\%$

User's Accuracies

MUC Class	Calculation	User's Accuracy
71	1 ÷ 1 x 100	100%
811	1 ÷ 4 x 100	25%
92	1 ÷ 3 x 100	33%
0222	2 ÷ 2 x 100	100%
1222	1 ÷ 1 x 100	100%
91	1 ÷ 2 x 100	50%
93	1 ÷ 2 x 100	50%
824	0	NA
4223	0	NA

Producer's Accuracies

MUC Class	Calculation	Producer's Accuracy
71	1 ÷ 1 x 100	100%
811	1 ÷ 2 x 100	50%
92	1 ÷ 3 x 100	33%
0222	2 ÷ 2 x 100	100%
1222	1 ÷ 1 x 100	100%
91	1 ÷ 2 x 100	50%
93	1 ÷ 1 x 100	100%
824	0 ÷ 2 x 100	0%
4223	0 ÷ 1 x 100	0%

They discussed how they might improve their map accuracies. One student thought that it might be a good idea to create a new clustered image using more clusters than the 10 they originally used. She thought that maybe their area had a greater number of different land cover classes than 10 and that with a larger number of clusters, fewer sites would be mis-classified. Another student agreed, but also suggested collecting more *Land Cover Sample Sites*. He observed that many classes only had one validation site. He thought that with more sites, a better accuracy assessment could be made. Everyone in the group agreed and they decided to pursue both suggestions.

Welcome Introduction Protocols Learning Activities Appendix

Land Cover Change Detection Protocol

Purpose

Using Multispec software, evaluate and investigate changes that have occurred in the major land cover types of your GLOBE Study Site by examining the digital files of two Landsat satellite images that were acquired a few years apart.

Overview

Using MultiSpec software, students compare two registered images, acquired several years apart, of a GLOBE Study Site and identify changes in land cover.

Student Outcomes

Science Concepts

Life Science

- Organisms can change the environment in which they live.
- Earth has many different environments that support different combinations of organisms.
- All organisms must be able to obtain and use resources while living in a constantly changing environment.
- All populations living together and the physical factors with which they interact constitute an ecosystem.
- Humans can change ecosystem balance.

Geography

- How to use maps (real and imaginary)
- The physical characteristics of place
- The characteristics and spatial distribution of ecosystems
- How humans modify the environment

Scientific Inquiry Abilities

- Use land cover data and appropriate tools and technology to interpret change.
- Gathering spatial data and historical data to determine validity of change hypotheses.
- Identify answerable questions.
- Design and conduct scientific investigations.
- Develop descriptions and predictions using evidence.
- Recognize and analyze alternative explanations.
- Communicate procedures, descriptions, and predictions.

Level

Middle and secondary

Time

Two or three class periods

Frequency

One time, but may be an iterative process as you progressively investigate more areas within your GLOBE Study Site

Materials and Tools

- Computer
- MultiSpec computer software (provided by GLOBE or downloaded from the Web)
- 2 - Landsat TM registered image datasets of the 15 km x 15 km GLOBE Study Site (disks provided by GLOBE), one recent, one a few years old, acquired at approximately the same time of year
- Printed Landsat TM images of the 15 km x 15 km GLOBE Study Site from the datasets
- Student land cover type map(s) of the GLOBE Study Site
- Topographic maps of your area (if available)
- Aerial photos of your area (if available)
- *Introduction to the MultiSpec Program* and *Change Detection Tutorial*
- MUC data from previous land cover type map classifications

Preparation

Install the MultiSpec software on the computers students will be using.

Install the images on the computers the students will be using.

Familiarize yourself with MultiSpec and the *Change Detection Tutorial.*

Prerequisites

Review and practice the *Introduction to the MultiSpec Program* and the *Change Detection Tutorial.*

Land Cover Change Detection Protocol – Introduction

Compare the two satellite images of your GLOBE Study Site. One was acquired before the other. However, the images have been *registered*. Registration is when the images are lined up so that every point on one image can be placed on top and matched with the same point on the other image. What has changed between the images? Can you see changes in your community's size, shape or dominant land cover? Is your school still surrounded by the same land cover classes? Can you see more vegetated areas in an image? Has there been a big event, such as a flood, earthquake, drought, hurricane, tornado, etc., which has changed your landscape? Has the type or size of natural areas changed? Are there more houses on your way to school? Can you see evidence of these changes in your satellite images?

Work on your own or with a partner. Make a list of questions about what you see in the images. Is there anything that you would like to know about these images regarding the change you may see? Some changes may not be easy to see but they are there.

Narrow your list down to one question. Once you have a question, come up with a plan to answer your question. You will need to use the Field Guide for *Land Cover Change Detection Protocol* and/or some of the other *Land Cover Field Guides.* In the *Land Cover Change Detection Protocol,* you *composite* the two satellite images. Compositing is combining two registered images into one. After that, you use the MultiSpec software to look for change.

Scientists use the same process to answer their questions about changes in satellite imagery. First they look at different images. Then they come up with questions they have about the images. Once they have decided on one question, they use scientific protocols or field techniques to answer it. Scientists may have to add new protocols or use ones that have already been used. You can do the same thing in GLOBE with the *Land Cover/Biology Protocols.*

Land cover change maps are a major product created from remotely sensed data. Keeping track of change is important to our understanding of the earth as a system. Knowing about these changes is the first step towards understanding why and where they happen. Change data can be used to update maps. It can also be used to estimate the rates of change in certain areas.

Teacher Support

The Measurement

The *Land Cover Change Detection Protocol* is the culmination of the *Land Cover/Biology Investigation*. In order to get to this point, students will have had to use the *Land Cover Sample Site* and *Biometry Protocols* to collect MUC data, and then used these data to create maps from their satellite image. In terms of understanding land cover, your students should be sophisticated and ready to be motivated to learn about the changes in their GLOBE Study Site that have taken place over time. They should be interested in tracking how future changes might influence the landscape. This protocol is the application of the protocols that have come before it and a point where there is room to incorporate other Investigations, if you have not already done so. The land cover of your GLOBE Study Site can influence temperature and in some cases, precipitation in your area. The history of the land cover can also influence the soil and the water bodies that are close to it. For example, heavily farmed areas that are now forest may have soil properties that indicate this. Currently farmed areas with high nitrogen levels in the soil can influence nitrogen values in a water body close to the field. It goes without saying that temperature, precipitation, soil and hydrology can also influence the types of land cover in an area. For instance, a drought can cause a field of herbaceous vegetation to die off. Tundra is not found near the equator. There are other relationships that you and your students may want to explore. The *Land Cover Change Detection Protocol* can be the starting point for exploring questions about such relationships. The student introduction can hopefully start your students thinking along those lines but they may also bring their own questions, such as how a new residential development in their neighborhood may influence their water supply or a neighboring wetland. Although the protocol directions themselves are simple, the true meaning of the protocol is in using it to identify and explore your students' questions about their changing landscape.

Obtaining Landsat Data

Your school may have already received more than one Landsat image; however, this protocol requires that the two scenes being compared be registered to one another and acquired at the same time of year. You may request scene pairs from GLOBE by contacting your Country Coordinator, US Partner, or the GLOBE Help Desk. Before making this request, your school must complete the *Computer-aided Land Cover Mapping Protocol* and have reported measurements for at least 10 Land Cover Sample Sites to GLOBE.

Teacher Follow-Up: For each band combination that you use to investigate change, use the **File** menu to save the image onto a disk as a TIFF file. If you have a color printer, print copies for comparison to your student-produced land cover maps. Students should prepare a summary on the nature of the changes they have discovered. Send copies of your land cover maps, change images, and student summary to the GLOBE Student Data Archive by following the directions given in the *How to Submit Photos and Maps* section of the *Implementation Guide.*

Supporting Measurements

All the *Land Cover/Biology Protocols*

Student Preparation

Have an understanding of MUC

Implementation of the *Land Cover Sample Site Protocol* at least 10 times

Completion and understanding of the *Computer-aided Land Cover Mapping Protocol*

Review and practice the *Introduction to the MultiSpec Program* and the *Change Detection Tutorial*

Helpful Hints

- When your students look at the two images, they might not see any major areas of change between them. This does not mean that change has not occurred, only that the changes are relatively small.
- Comparing a single Landsat channel between two years is helpful for looking at changes for different land cover types. Each channel has specific applications based on the spectral signatures of the different land cover types.
- If a pixel in the **newer** image is brighter than in the **older image**, that pixel will show **green**. This means an **increase** in the property being measured.
- If a pixel in the **older** image has a higher reflectance, the red and blue will produce **magenta**, indicating a **decrease** in the measured quantity in the newer image.
- Since strong visible reflectance is often associated with exposed mineral materials (urban development, rocks, bare ground) we might infer that in a (1, 6, 1) combination, green areas have undergone an increase in urban development. Landsat channel 1 (blue) is useful for human-made features.
- It is important to consider the time of year each satellite image was acquired. Most of the time, your images will be at the same time of year but there may be a few crucial weeks of difference between them. For example, in one image, the leaf foliage may not be completely out or certain crops may not have been planted in agricultural fields. In a (4,9,4) combination, when green areas in two different images taken at different times of the year are evident, we are faced with the problem of deciding how much of the change is due to a real increase in vegetated area, and how much is due to seasonal variations. (See the example in the Durham, NH, images in the *Change Detection Tutorial*.)
- If we can find locations that appear to show an increase in vegetation in the newer image, we might infer more strongly that these represent areas of real vegetation increase. Conversely, areas of magenta in the newer image that appear green in the older image could represent areas of vegetative decrease. Landsat channel 4 (near infrared) is useful for vegetated areas.
- Have your students fill in the names of the files they will be using on their *Field Guide*.

Questions for Further Investigation

- Which land cover type (MUC class) changed the most? What are some causes of this change?
- Generally, was there an increase or decrease in vegetation?
- Look at other areas of change. Try to explain why these changes occurred. Are these changes because your satellite images are from different time periods (i.e. summer vs. winter, drought vs. rainy season), or was there human influence, or a major environmental event (i.e. fire, flood, etc.)?
- How can you use this change information to help your community?
- How would your satellite image change if you compared different seasons? How would the composite image appear?
- What is the effect of temperature and precipitation in the time immediately preceding the images? Students will have to research this question.
- If you live in a coastal region, what is the effect of the position of the tides? You will have to research the times of high and low tides on the dates of your images. Remember that Landsat images are acquired in the morning.

Change Detection Protocol

Field Guide

Task

Use MultiSpec to combine the digital data for two images of your GLOBE Study Site (acquired a few years apart) into one composite image and analyze the composite to learn about the land cover type changes that have occurred.

What You Need

- ❑ *Introduction to the MultiSpec Program* and the *Change Detection Tutorial*
- ❑ MultiSpec computer software
- ❑ MUC data from previous land cover type map classifications
- ❑ 2 - 512 x 512 pixel Landsat TM registered image data of the 15 km x 15 km GLOBE Study Site (disks provided by GLOBE), one recent, one a few years old
- ❑ Computer

What To Do

1. Compare the hard copies of the Landsat TM images from the two different dates. What are the differences that you see between them?
2. Start the MultiSpec program on the computer.
3. From the **File** menu, select **Open Image.**
4. Select and open the older image of your GLOBE Study Site. It is labeled ___________________. Follow the defaults in the *Change Detection Tutorial.*
5. Select and open the newer image of your GLOBE Study Site. It is labeled ___________________. Check the **Link to Active File** box.
6. Reformat, name and save the new image (called _________________) using the directions in the *Change Detection Tutorial*.
7. Open the new image and follow the directions in the *Change Detection Tutorial* for saving the statistics.
8. Examine the image for change by following the defaults in the *Change Detection Tutorial.*
9. Save the developed land cover image (1, 6, 1) and the vegetative image (4, 9, 4) used for comparison as TIFF files. See you teacher for further instructions on submitting them to GLOBE.

Looking at the Data

Are the data reasonable?

After you have completed the production of your Land Cover Change Image, you will have drawn some conclusions about which land cover types have shown increases or decreases in the time between your two images. Land cover changes in both space and time. Some of these changes, such as the process of succession in a wooded area, are natural. Others are "anthropogenic," that is, produced by human beings. To determine whether these apparent changes are reasonable, use the substantial amount of data collected with the *Land Cover Sample Site Protocol*. The Land Cover Sample Sites that you visited will help to determine the accuracy of your land cover maps. If you find that you need more data than you have, simply use the protocol to collect more.

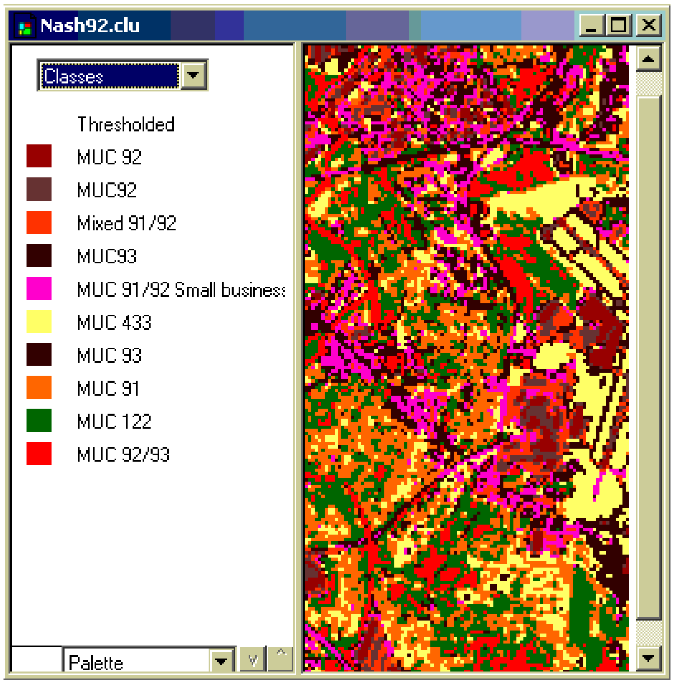
For example, if your change image appears to show large increases in urban areas within your GLOBE Study Site, you will need to visit these areas to determine if this is really the case. Remember that some kinds of features appear very similar in Landsat images. Clouds, beach sand, and highly developed urban areas all appear similar, and may not be well distinguished. Since you are the experts for your GLOBE Study Site, you can use your own familiarity with the area to help you determine if the changes shown are reasonable.

What do scientists look for in these data?

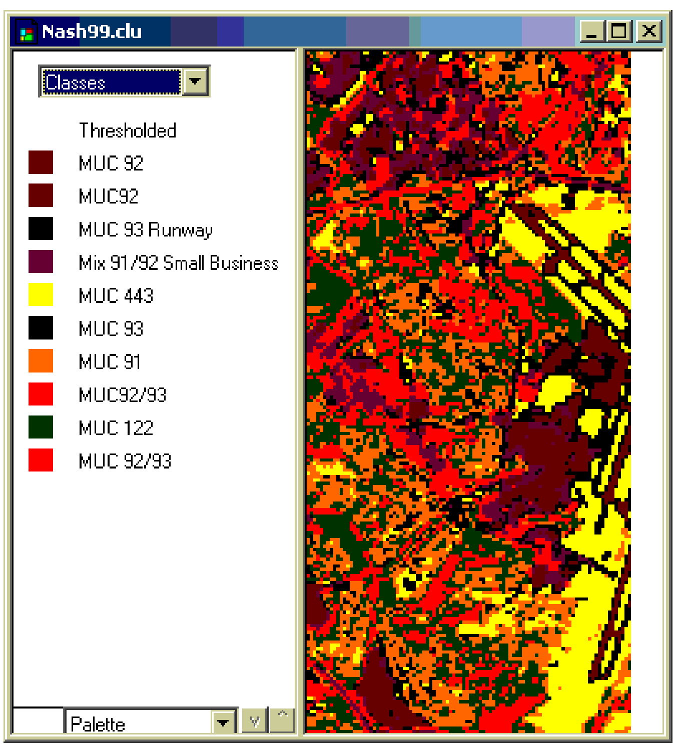
Environmental scientists use land cover data to help develop computer models for everything from atmospheric circulation to the uptake of Carbon by different parts of the environment. Often, remotely sensed images are used to determine land cover. If the images used are not up-to-date, they do not provide accurate input to the models. Also, scientists must often estimate land cover types without visiting the area in question. Your data on land cover change can help scientists fine tune their models. These data are also very valuable to local community planners who are not always able to see change over as large a scale as you can. To adequately understand what has happened, and to help predict what may yet occur, scientists need to know what changes have occurred, and how much time was needed for those changes. From these data, rates of change can be calculated. It is rates and directions of change that help us to predict what may happen next.

An Example of Student Inquiry

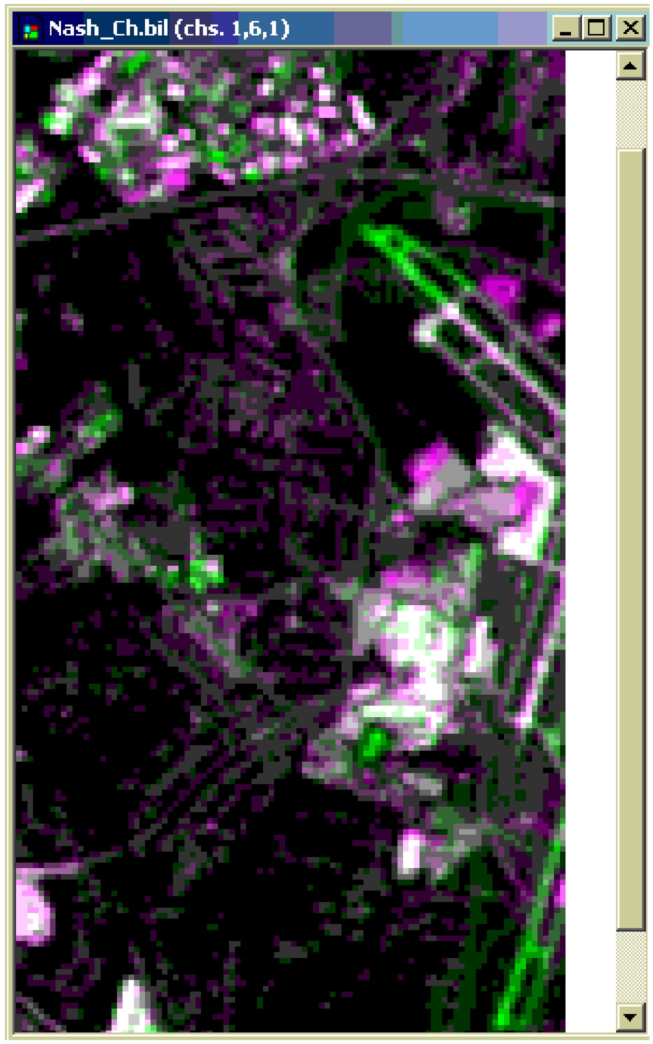
Students in the Nashville, Tennessee, area were investigating change over time around the Nashville International Airport. They knew that during the time between their Landsat 5 and 7 images, the runways at the airport had been lengthened. This group created a computer-assisted land cover map of a portion of their 1992 image that included the airport.



The group then created a map for their 1999 image of the same area.



Examining these maps, they were certain that significant growth had occurred in the airport area over the time between the images. They used the *Change Detection Tutorial* to produce a change image.



The group found that the change image indicated development at the airport. They could see the change represented as the green areas at the ends of the runways, They were also interested to see that there were other areas of green, or change. They thought that this might indicate places where there was urban-type development. They knew that magenta (purple) areas suggest places in which there may have been a decrease in developed-type land covers. The MUC 91 areas (residential) showed this. The group wondered if that was due to the growth of trees around homes. They decided that they should visit these places to explore their ideas further.

Fire Fuel Protocol

Purpose

To measure the different types of fuels (i.e., dead branches, logs, live shrubs and trees) for fires in land cover sample sites

Overview

In a homogeneous land cover sample site, students measure tree, shrub and herbaceous cover and heights. Using a compass and tape measurer, students walk along transects and count the different sizes of downed woody fuel types. Students use clinometers to measure the overall slope of the site as well as the slope of each transect.

Student Outcomes

Students learn about the different types of living and dead organic materials that can become fuels for wildland fires.

Science Concepts

Physical Sciences

Objects have observable properties that can be measured using tools.

Life Sciences

Ecosystems demonstrate the complimentary nature of structure and function.

Geography

Physical processes shape the environment.

Science Inquiry Abilities

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and explanations using evidence.

Recognize and analyze alternative explanations.

Communicate procedures and explanations.

Time

2-3 hours excluding travel time

Field time will lessen with experience

Level

Middle and Secondary

Frequency

Collect data once for each site.

Multiple Fire Ecology Sites are desired.

Materials and Tools

GPS Data Sheet
GPS Field Guide
Fire Fuel Center Plot Data Sheet
Fire Fuel Center Plot Field Guide
Fire Fuel Transect Measurements Data Sheet
Fire Fuel Transect Measurements Field Guide
MUC Field Guide and/or *MUC Glossary of Terms*
Data Sheets and *Field Guides* for *Biometry* and *Land Cover Sample Site Protocols* in the *Land Cover/Biology Investigation*
GPS
Wooden stakes
Flexible tape measure, at least 30 meters
Compass
Clinometer
Camera
Tree guides
0.5-0.65 cm wooden dowel
2.5 cm wooden dowel
2 clear rulers in mm
Meter stick
Trowel
Clipboard
Pencils or pens
Flagging
Landsat image, topographic map, other maps of area (optional)

Preparation

Locate a Fire Fuel Site.

Practice using the *Land Cover Sample Site* and *Biometry Protocols* in the *Land Cover/Biology Investigation*

Learn about the different fuel classes.

Fire Fuel Protocol – Introduction

Why measure fire fuels at land cover sample sites?

For thousands of years, fires have shaped the wildlands in many places around the world. But wildland fires can be very different. For instance, fires burn grasslands every year, while certain forests and wetlands escape fire for centuries at a time. In forests, fires may burn only grass and low shrubs under large trees or nearly every tree may be killed. Fires can produce a mosaic of fire-killed trees and patches left unburned because of random changes in wind direction or other conditions (Brown and Smith, 2000). The outcome of fire is unpredictable and plays out differently in nearly every plant and animal community.

Many plant and animal species continue to persist for thousands to millions of years although their ecosystems are periodically ravaged by fire, and some species even thrive when their homelands burned at predictable intervals. Not surprisingly, certain plants and animals have evolved traits that enable them to take advantage of fire to reproduce successfully or compete with other species (Miller, 2000). Some wild plants and animals are actually harmed if fire is excluded from their habitat. In these environments, land managers often attempt to reintroduce fire and take advantage of naturally occurring fires to benefit these landscapes. Professional programs that include preventing fires, putting them out where they are likely to produce damage, and using them to benefit the land is called fire management.

Wildfire scientists refer to all the organic plant matter above the ground as fuel. The amount and kinds of fuel help determine how far and fast a fire spreads, and the relative fraction of live and dead plants are burned. Student measurements will help scientists make better models for calculating fire risk. These improved models could save lives, protect property, and improve fire management. As well, your data can be used to calibrate detailed fuel maps created from satellite imagery.

In addition, the measurements you take can be used for other types of research and management. For instance, the estimates of live and dead biomass made from your measurements are extremely important for understanding carbon, water and nutrient cycles. Potential smoke and carbon inputs to the atmosphere can be calculated from the loadings of fuels computed from your data. Maps of the habitats for mammals, birds, reptiles, amphibians and insects that utilize coarse woody debris (the downed logs) can be made.

What are fuels?

Fuels are the above ground organic biomass that can contribute to a wildland fire. Fuels are usually classified by whether they are live or dead, woody or herbaceous, and size. The classes of fuels used in this protocol are shown in Table FF-1.

We classify fuels as either live or dead because of their differences in moisture content. Moisture content in fuels plays a major role in fire behavior. Live fuels are living plants extracting water from the soil. Since live fuels are constantly extracting water from the ground, their moisture content tends to be quite high. Dead fuels no longer manufacture food or circulate water so their moisture contents are more closely linked to atmospheric conditions.

Live fuels are separated into trees, shrubs and grasses. Shrub fuels include all those living woody plants, including young trees that can burn during a fire. Herbaceous fuels include all non-woody plants such as grasses, sedges, forbs, and ferns. In the MUC definition (see *Land Cover/Biology Investigation*), trees are defined as woody vegetation greater than 5 meters tall.

Dead fuels can be parts of living plants or dead organic material lying on the ground. Dead woody fuels found on the ground are called downed. Dead woody fuels are the most important for the spread of wildfires and the most influential for how a wildfire behaves. Downed dead woody fuels are divided into size classes based on the diameter of the fuel particle (Table FF-1). These diameter classes were developed to describe the time it takes for the woody particle to dry. Other dead fuels can be the suspended dead plant parts from live trees, shrubs, or grasses. The weight or mass of dead or live fuels per unit area (e.g., kg m^{-2}) is called loading, and fuel loading is one of the most important quantities that will be calculated from the data you collect.

Fire Behavior and Effects

Fire behavior is the way a fire reacts to its surroundings. How a fire behaves depends on the "fire environment", a term used to describe the type and amount of fuels present, weather, and topography in an area. The most commonly used fire behavior characteristics are fire spread (how fast a fire moves) and fire intensity (the flame length). Sometimes even the most intense fires do not heavily impact the environment, and sometimes the smallest flames can kill many plants. The term, "fire effects", is used to describe the damage or influence a fire has on the biota. In addition, the term, "fire severity", is the damage that heat from fire can have on living organisms above and below ground. Low severity fires kill few living flora and fauna, but they may have high fire intensity and fast spread rates. The potential fire behavior and fire effects cannot be predicted without an accurate description of the fuels.

Table FF-1: Fuel Types and Size Classes Used in Fire Management. The classes of fuels used in this protocol. The diameters of the downed wood are often referred to the average length of time it takes to dry the wood.

Fuel Type	**Size** (twig, branch, or trunk diameter)	**Description**
Crown Foliage	Any	Living and dead crown foliage including needles and broad leaves
Crown Branchwood	0 to 3 cm	Live and dead crown woody branches
Shrub — Live	Any	Living woody plants – trees and shrubs less than 2 meters tall
Shrub — Dead	Any	Dead shrubby material suspended above ground. This includes trees and shrubs less than 2 meters tall.
Herbaceous - Live	Any	Live herbaceous plants including grasses, sedges, forbs, ferns, and lichen
Herbaceous — Dead	Any	Dead herbaceous plant parts above ground
Litter	None	Recently fallen needles, leaves, cones, and bark
Duff	None	Partially decomposed organic material below the litter layer
Downed Woody	0 to 1 cm	Takes 1 hour to dry woody twigs and branches
	1 to 3 cm	Takes 10 hours to dry woody twigs and branches
	3 to 8 cm	Takes 100 hours to dry woody branches
	8 + cm	Takes 1000 or more hours to dry branches and logs

Teacher Support

Site Selection: Where and When

The measurements are taken within a homogeneous area of land cover that is at least 90 meters by 90 meters in size. Refer to the *Land Cover/Biology Investigation* for more discussion. Fuels are often correlated with the surrounding plant community and topographical setting. It is best to confine your fuel sampling to an area that has similar vegetation characteristics along with similar slope, aspect, and elevation. Aspect is the general direction the slope the sample site faces. This homogeneous area is often called a stand in ecology or forestry. Stand characteristics can change over a very short distance, sometimes within 3 to 5 meters. Take measurements at your site that best represents the conditions in the stand based on the living vegetation (species composition, plant structure, plant size, canopy closure), the stand's history (stumps, burned logs, fire scars), ground characteristics (fuel loadings, duff depths), and topography (slope, aspect, elevation).

The protocol asks students to measure canopy cover. Because of this, the best time to perform the protocol is when the leaves are open.

Measurement Procedures

Sampling for the *Fire Fuel Protocol* is divided into two parts. One set of measurements is made within a center 30 x 30 meter plot and a second set of detailed measurements is made along other transects outside the plot. For the center plot measurements, students will take measurements following *the Land Cover Sample Site Protocol* and *Biometry Protocol* in the *Land Cover/Biology Investigation.* In addition, students will be taking slope, aspect, and average stand and crown heights. The second group following the *Fire Fuel Transect Protocol* will be taking a different set of measurements. The Fire Ecology measurements can be taken in all natural MUC land cover types (MUC 0,1, 2, 3, 4, 5, and 6) except open water (MUC 7).

There are two versions of the field guide: a more descriptive classroom preparation guide and a short field guide. The classroom preparation guide provides more background on how to do the measurements and the students can use this version to practice and become comfortable with taking the measurements. The other version provides a list of shorter directions to be used in the field.

True rather than magnetic compass directions are used. Refer to the *GPS Investigation* to learn how to correct for magnetic deviation in your area.

Mark the tape with brightly colored paints or flags at the 5-meter, 7-meter, 10-meter, 15-meter and 25-meter marks so that you can easily identify where you are on the transect when sampling.

Secure an 8-10 cm nail to the zero end of the tape with string or wire making sure the tape doesn't move. Drive this nail into the ground at the beginning of a transect. The nail should be short enough to be pulled out of the ground by pulling on the 25-meter end of the tape, but long enough to keep the tape from moving or dislodging at the slightest tug. The use of the nail allows fuel sampling with only one person. Once the person has traversed the entire length of the transect, he or she can simply pull the nail out of the ground by tugging on the 25-meter end, and begin the next transect.

Student Management

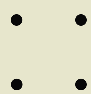
You may want to divide your students into two main groups (one for the center plot and the other for the transects) and allocate responsibilities for each group. There are separate field guides and data sheets for the plot and detailed transect measurements.

A two- or three-person fuel sampling team is recommended per transect. More people often trample the fuel bed, which can make the measurements inaccurate. A single person can perform these measurements but will have a difficult time collecting these data until experienced with the methods.

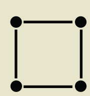
Each team should have two wooden dowels each with a different diameter. The first dowel should be from 0.5-0.65 cm in diameter. This is used to determine the diameters of the 0— 1 cm class (1-hour fuels). The second dowel is 2.5 cm in diameter, which is used to measure the diameter of 1 – 3 cm class (10-hour fuels). Refer to Table FF-1.

How to Count Fire Fuels

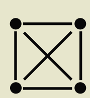
The following box illustrates an easy method to keep track of the fuel counts along transects. Instead of counting the intersects in your head and recording the final tally, try using a box tally method where you put a dot for each fuel intersect. The dots are arranged in a pattern that creates four corners of a box. Each dot is for one count for a total of 4 counts shown below.



Now each additional fuel count tally is a line connecting the dots. Each line is one count. The total in the picture is 8.



The final two tallies are crosses through the middle of the box. Each diagonal is one count.



Each completed box represents 10 fuel intersect tallies for that size class

Connections to Other Protocols

Land Cover/Biology: In order to do the *Fire Fuel Protocol,* students need to perform the *Land Cover Sample Site* and *Biometry Protocols*.

Atmosphere: The potential for fire is related to the atmospheric conditions such as temperature and precipitation.

Phenology: The amounts of dead and living matter are dependent on the time of year, particularly if there is a distinct wet and dry seasonal pattern, or cold and warm seasons at your locality.

Helpful Hints

Putting completed *Data Sheets* in plastic bags in the field will help to keep the forms from getting wet or dirty.

Questions for Further Research

Is fire common in your area? If so, what kinds of adaptations have plants and animals made for these environments?

What time of year do wild fires most occur in your area? Why?

Are certain land cover types more susceptible to fire?

After a fire happens in your region, what types of plants first grow there?

Welcome Introduction **Protocols** Learning Activities Appendix

Classroom Preparation Guide for Fire Fuel Center Plot Measurements

Overview

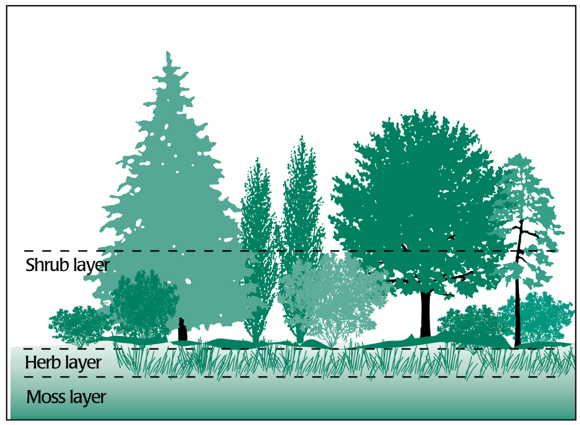
One set of measurements is taken within a 30 x 30 meter area within your homogeneous site, like that described in the *Land Cover/Biology Investigation*. These measurements describe the general characteristics of the stand as a whole. A second set of measurements is taken on several fuel transects around the center plot. These fine scale measurements will describe the fuel loadings, live and dead shrub and herbaceous cover, and duff and litter depth.

In the Field

The center 30 x 30 meter plot

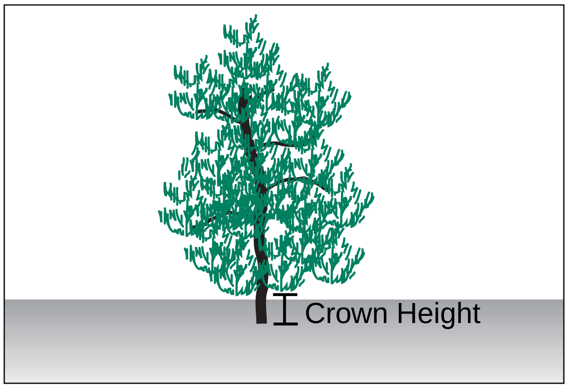
1. Do the *Land Cover Sample Site* and *Biometry Protocols* in the *Land Cover/ Biology Investigation.* Identify latitude, longitude and elevation using a GPS, take photos and identify the MUC class. Do the full set of biometry measurements: ground and canopy cover, tree and shrub heights, dominant and codominant tree and shrub species identification.
2. Measure the aspect of the site. Aspect is the general direction the slope of the site faces. This is measured by standing perpendicular to the slope of the site with your eyes facing uphill. Measure the direction with the compass (1-360 degrees). Be sure to enter the true (not magnetic) directions. An aspect value of zero is entered for flat stands with no slope. 360 degrees is used for true north.
3. Work with another student who is approximately your same height. Measure the angle of the slope of the site by aiming your clinometer downhill 25 meters away. Look through the straw of the clinometer and locate the eyes of the other student. Record the angle on the *Fire Fuel Transect Measurements Data Sheet*. If you are looking downhill, turn the clinometer around, locate the eyes of the other student and record angle. Then, look upslope and repeat the procedure. Record second slope value.
4. Estimate the average stand height. The average stand height is the average height of all trees or shrubs in the dominant tree stratum. The forest canopy is composed of layers or strata that are defined by the heights of the associated trees and shrubs.

Figure FF-1: Demonstration of a Plant Strata in a Forest Community



   There needs to be at least 10 percent canopy cover to define a stratum. Sometimes the dominant stratum is composed of trees and shrubs of variable heights. You can estimate this with your eyes. To make a better estimate, you can use the clinometer or tape measure to measure a few trees or shrubs heights in the dominant stratum. If the trees or shrubs you already measured are in the dominant stratum, then calculate the average stand height from those measurements.
5. Estimate the average crown height. The average crown height is the average height of the live crown base of the lowest tree/ shrub stratum (i.e., to the bottom of the crown of the lowest tree/shrub stratum). Again, there needs to be at least 10 percent canopy cover to be considered a stratum. Because the crown heights can be very variable, you should measure and record the crown base heights of all trees/

Figure FF-2: Crown Height is the Distance from the Ground to the First Branches



shrubs in the lower layer and then calculate the average. If the crowns are close to the ground, use a meter stick or flexible tape measure to measure the crown heights. For taller trees use the clinometer to measure heights following the method described in the *Land Cover/ Biology Investigation*. Sometimes, the crowns of trees/shrubs will touch the ground, and if there is over 10 percent cover of trees/shrubs that touch the ground, a crown base height of zero is recorded on the *Fire Fuel Center Plot Data Sheet*.

6. Record any comments that may be relevant to the fuels data. Include knowledge of stand history (grazing, fire, timber harvesting evidence), unusual stand conditions (e.g., insect and disease infestations, animal browsing), and problems with sampling (e.g., slope too steep for secure footing). Write a generalized description of the location of the site. Include estimates of distances and azimuths from roads, trails, and rivers, and record any place names that might be relevant.

Detailed Measurements Along Transects

Overview

The number of transects you take measurements will vary, from 3 to 7, depending on how many fuel particles cross your transects.

This fuel transect methodology uses a planar approach pioneered by van Wagner (1968) and improved upon by Brown (1974). This procedure uses a sampling plane to count all the intersections of downed woody fuel (Figure FF-3). The sample plane starts at the ground surface and extends 2 meters vertically above the ground surface. All downed woody fuel particles (twigs and branches) that intersect that plane are counted. Visualize a pane of glass that extends 2 meters upward from the ground where every woody twig or branch that the glass slices gets counted (Figure FF-3). Place a flexible tape along the ground and that becomes the bottom of your sampling plane that extends 2 meters high. Since often the ground is not flat, the top of the sampling plane wavers with the topography of the ground surface.

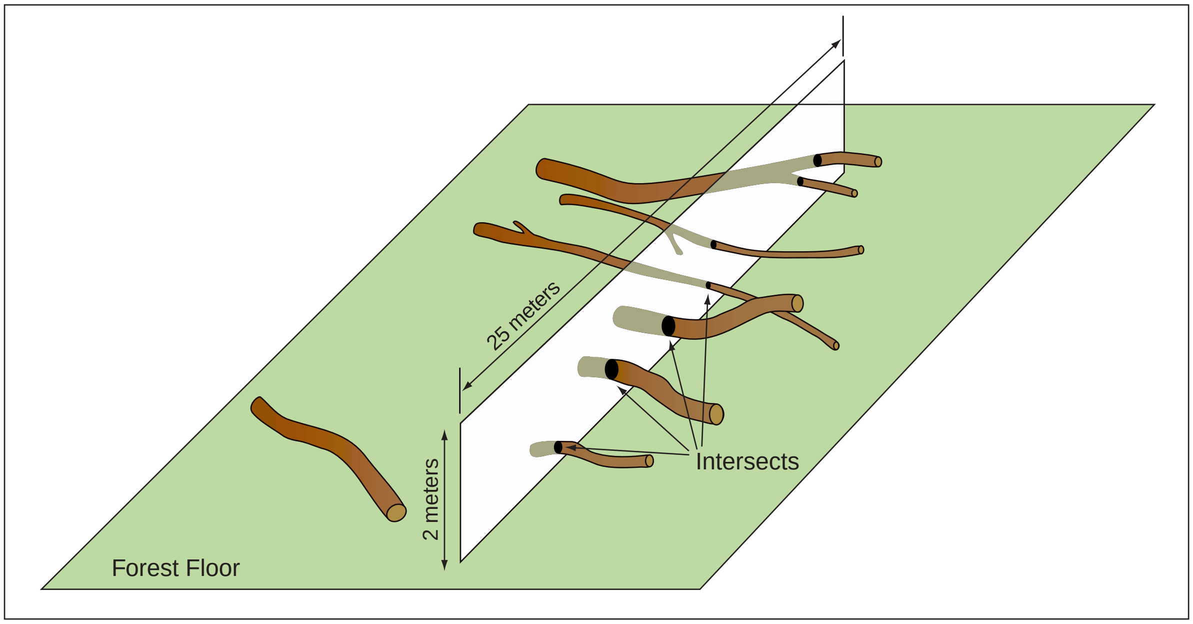
Downed woody fuels intersecting the sampling plane are counted in four size classes of 0 - 1 cm diameter, 1 - 3 cm diameter, 3 - 8 cm diameter, and 8+ cm in diameter (Table FF-1).

In the Field

Part 1: Measurements taken between the 5-meter and 15-meter marks along a transect

1. Drive the attached nail at the zero end of the tape into the ground next to center flag or stake. All fuel transects are 25 meters long but fuel intersections (where twigs and branches cross the transect) will be counted from the 5 to 25 meter marks. The first 5 meters is skipped to avoid excessive trampling of fuel bed near the center. The tape is stretched due EAST (90 degrees azimuth from the center of the site). The tape need not be level because fuels are estimated along slope distances rather than horizontal distances. You can wrap the other end of the tape (after 25-meter mark) around a tree or shrub, or

Figure FF-3: Important Line Transect Distances for Fuel Measurement

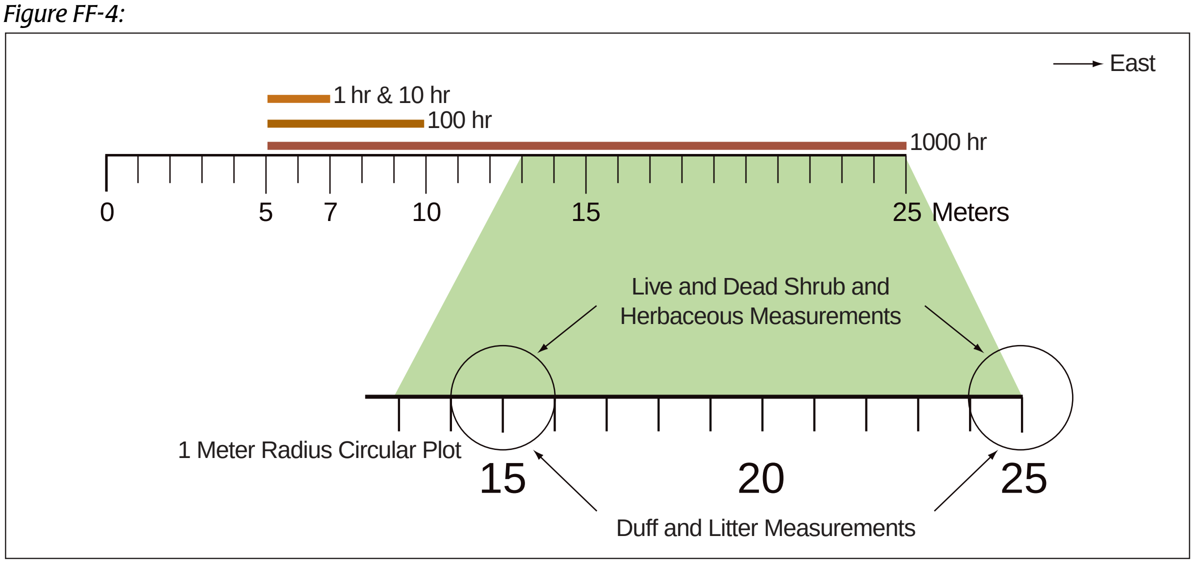


lightly anchor it to the ground with another nail. Keep the tape as taut and straight as possible. You may attach another nail at the 30-meter end of the tape but this prevents rapid coiling or reeling of the tape after you are finished. Be very careful not to disturb any fuels along the entire length of the tape, especially between the 5- and 10-meter marks. Many people have a tendency to shuffle along the line and kick the downed woody particles.

Figure FF-4 below illustrates where the Fuel Measurements are taken along each transect.

- From the 5-meter to 7-meter mark, sample all fuels that cross the sampling plane: the 0 – 1 cm twigs, 1 - 3 cm twigs and branches, 3 - 8 cm branches, and 8+ cm logs.
- From the 7-meter to 10-meter mark, count the 3 – 8 cm and the 8+ cm logs.
- From the 10-meter to 25-meter marks, only count the 8+ cm logs.

Figure FF-4:



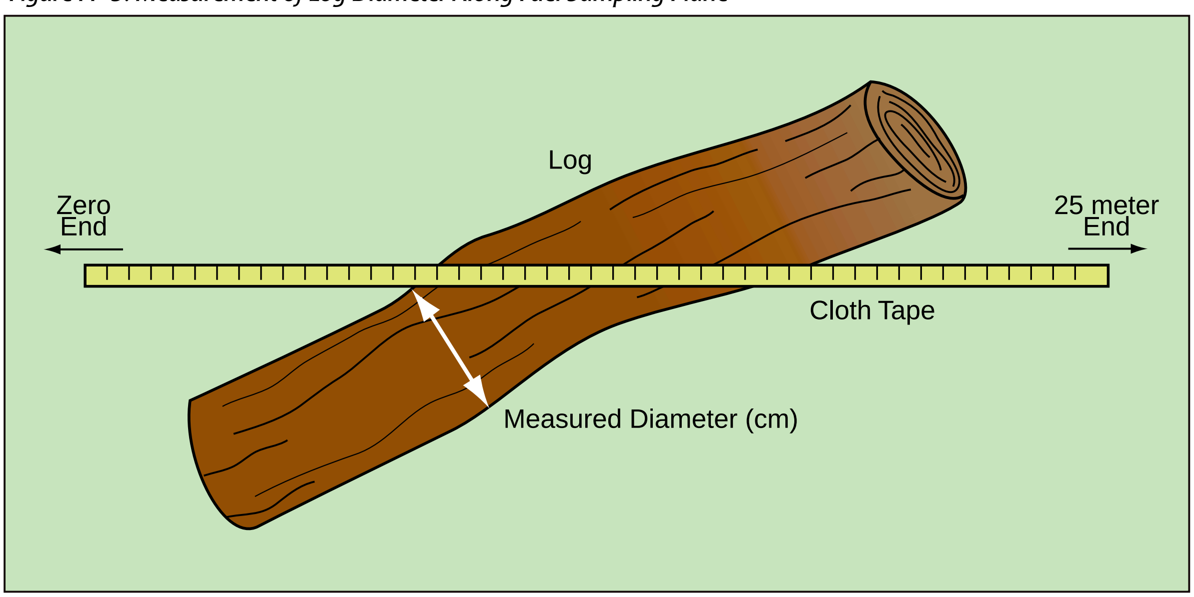
2. Work with another student who is approximately your same height. Stand at the start of the transect. Your partner stands at the 25-meter mark. Look through the straw of the clinometer and locate the eyes of the other student. Record the angle on the *Transect Measurements Data Sheet*. If you are looking downhill, turn the clinometer around, locate the eyes of the other student and record angle.
3. Walk to the 5-meter mark on the tape and start counting the downed woody fuel intersects. Figure FF-4 shows the sampling strategy.

Measuring fuels is quite simple. All you need to do is count the number of downed woody particles by size class that cross the vertical sampling plane (see Figure FF-3). Remember, the diameter of the fuel particle is determined where the particle crosses the sampling plane. Use the wooden dowels to decide the size of each woody fuel particle that intersects the plane. Use the clear plastic ruler to measure the 8+ cm logs. Do not count fuels below the litter layer (sunken in the ground), or if the dead woody fuel is attached to a live plant. Also, be careful to only count woody material. Many herbaceous stems look like twigs once they are on the ground, so pick up a few questionable twigs and snap them in two to make sure the center is solid wood. Also, be sure not to tally needle intersections, especially large needles such as those fallen from pine trees.

If you are working in a group of 3, each person can keep track of one size of fuel as you walk along the transect. Then all the size class of fuels, except the largest (8+ cm) can be counted at once. If you are working in a group of 2 or by yourself, sometimes it helps if you count only one fuel type (e.g., 0 – 1 cm) first, then go back and count the 1 – 3 cm and 3 – 8 cm fuels. This is especially helpful if you are in heavy fuel loadings. Be careful not to disturb the fuels.

4. Measure the diameter of the 8+ cm logs to the nearest centimeter by laying the clear plastic ruler along the log cross section, perpendicular to the long axis of the log at the point where the vertical sampling plane intersects the log (Figure FF-5). Sometimes, the tape may be oriented nearly parallel to the log, so you will need to take the log diameter where the tape first touches the log from the zero end.
5. Measure the log decay class for each log 8+ cm in diameter. Five log decay classes are used to describe the stages of decay for each log. These classes are important because heavily decayed logs are difficult to ignite and do not contain as much

Figure FF-5: Measurement of Log Diameter Along Fuel Sampling Plane



biomass as sound logs. Classes 1, 2, and 3 are called sound logs because when you kick them, no parts of the log are dislodged. Classes 4 and 5 are called rotten logs because when you kick them they break apart or a piece of the log becomes dislodged. Record both the diameter and log decay class on the data sheet for each log.

- Class 1 is for newly fallen logs where the leaves are still on twigs attached to the logs, and the logs are still green (contain fresh sap).
- Class 2 logs have no leaves but still contain the bark and a majority of small and large twigs and branches. The logs have dried centers and there is no sign of fresh sap or live tissue.
- Class 3 logs do not have any bark and have lost most twigs and branches. These logs are typically gray and their centers have not yet rotted.
- Class 4 logs are still somewhat intact and, when you kick them, only small pieces become loose. Be sure to measure the log diameter before you kick to determine rot class. Often the inside of the logs have rotted and the outside shell is the only part of the log still somewhat sound.
- Class 5 logs are fully rotten and often completely fall apart when you kick them. Sometimes it is difficult to identify a rotten, Class 5 log because it is so decomposed it seems part of the litter and duff. Do not measure these Class 5 logs because they act more like duff than logs when they burn. A good way to decide whether or not to measure a Class 5 log is to estimate if the log has collapsed to less than half of the original diameter where it crosses the tape. If the rotted diameter is less than half the original, then do not consider it a log and skip it.

Note: Do not measure the following:

- Dead limbs extending from standing live or dead trees or shrubs.
- Stumps and roots because they rarely burn in a wildland fire.
- Logs that intersect the sampling plane above 2 meters. This especially means those dead tree trunks or branches leaning over the sampling plane. If tree trunks lean below the 2-meter height, then record them as downed logs as long as they are totally dead.

6. After collecting the data between the 5- and 7-meter marks, walk to the 10-meter mark. Count the 3 – 8 cm and the 8+ cm logs. Measure the diameters and identify the rot class of the 8+ cm logs.
7. Walk to the 15-meter mark. Count the 8+ cm logs. Measure the diameters and identify the rot class of the 8+ cm logs.

Part 2: Measurements taken at the 15-meter mark

8. At the 15-meter mark estimate the depth of litter and duff, and the cover and height of live and dead shrub and herbaceous plants. Cover is estimated within a circle with a 1-meter radius. The center is at the 15-meter mark. Here is what you do:

First, estimate the vertically projected cover of live shrubs in the 1-meter radius circle. Shrubs are

Table FF-2: Cover Classes

Cover Class	Percent
01	Less than 1 %
03	1 to 5%
10	5 to 15%
20	15 to 25%
30	25 to 35%
40	35 to 45%
50	45 to 55%
60	55 to 65%
70	65 to 75%
80	75 to 85%
90	85 to 95%
99	95 to 100%

those plants that have woody stems and include some of the creeping vine-like plants on the ground and young, short trees (called tree regeneration). Check the plants to see if they have woody stems. Use the cover classes listed in Table FF-2.

Two points on that circle are already provided for you by the 14- and 16-meter marks. However, you will need to estimate, by eye, the radius of the circle perpendicular to the tape. A good way to do this is to stand directly above the 15-meter mark and extend your arms outward. Be sure to measure your arm span and adjust your estimates. Confine the cover estimate of live shrubs and tree regeneration to the 2-meter height limit.

a. Now inspect the shrubs and tree regeneration more closely. Notice the dead material still attached to the shrubs and small trees. This includes dead leaves, branches, flowers, and so on. Try to estimate the cover of these dead plant parts using the same cover classes. Do not add those shrub branches that are unattached and lying on the ground.
b. Estimate the average height of the live shrubs within your circle. Find the shrub layer that has the most (greater than 50 percent cover) canopy cover and measure the vertical height from the top of the litter layer to the height of the dominant layer. Shrub heights can be quite variable. A quick way to estimate shrub heights is to accurately measure the heights of your ankle, knee, and waist so you can use those known heights to estimate the plant heights. A better way is to measure plant heights with a meter stick. Enter heights that are less than 5 cm as zero.
c. Next, look around your 1-meter radius circular plot and estimate the percent cover of live herbaceous ground cover using cover classes in Table FF-2. Include all ferns, moss, grasses, sedges, lichens, and forbs below the 2-meter height threshold.
d. Then, estimate the percent dead herbaceous ground cover using the same cover classes.
e. Estimate the height of the live herbaceous layer using the meter stick.
f. Estimate the height of the dead herbaceous layer using the meter stick.

9. Still at the 15-meter mark, you next measure the thickness of litter and duff. Litter and duff burn differently and both are needed to accurately predict fire consumption. Litter is generally consumed by flaming combustion while the duff is consumed by smoldering combustion. Litter is composed of freshly deposited leaf, needle, and other plant parts, while the duff is made up of decomposing organic matter. Plant parts can be identified in the litter, but not so easily in the duff. The duff is generally moist, heavy, dense, and dark, while the litter tends to be drier, less dense and lighter color. It can be difficult to estimate where the litter stops and duff starts. So do the best you can.

   The depth of the litter and duff layer is measured at the 15-meter mark at approximately 20 centimeters to the right of the transect as you are looking from the zero end towards the 25 meter end (i.e., the south side of the tape on the first transect). If there is a tree, log, rock, or stump at the 20 cm offset distance, take a measurement 20 cm to the left of the transect. If a suitable sampling place is still not available, pick a place as close to the 20 cm distance as possible that is somewhat representative of the duff and litter layer characteristics within the 1-meter radius plot. Do not go beyond 30 cm from the 15- meter tape mark on either side of the tape. If no place is available to measure duff and litter, enter zero for total litter and duff depth and duff depth on the *Fire Fuel Transect Measurements Data Sheet*.
   Litter and duff depths will be highly variable across a stand so be prepared for a wide variety of measurements. Duff and litter depths generally increase near trees, especially near tree stems where needles

and leaves accumulate. Be sure to dig all the way to the mineral soil surface because sometimes the duff and litter layer is so deep that it is often hard to tell when you hit the mineral soil interface. This is especially true when the depth measurement has to be taken directly where a log has been decomposing to form a seemingly deep duff layer. If unsure where the mineral soil starts, try digging a test hole just down the tape (towards the zero end) to make sure you know what the mineral soil looks like and what conditions might indicate where the mineral soil starts.

a. Use the garden trowel to cut through the litter and duff layer to the mineral soil.
b. Pull one side of the cut layer away to reveal the litter/duff profile.
c. Place the clear ruler against the profile with the zero end of the ruler at the bottom of the profile. Measure the depth of the entire profile. Record the depth on the *Fire Fuel Transect Measurements Data Sheet*.
d. Next, slide your finger down the ruler until it touches the top of the duff layer. Grasp the ruler tightly without moving your finger and bring the ruler up to your face so that you can read the centimeter scale at the bottom of your finger. Record the depth of the duff layer.

Part 3: Measurements taken between the 15 and 25-meter marks

10. Walk to the 25-meter mark. Count all the 8+ cm diameter logs that intersect the transect up to 2 meters high. Measure the diameters and identify the log decay class of the 8+ cm logs.

Part 4: Measurements taken at the 25-meter mark

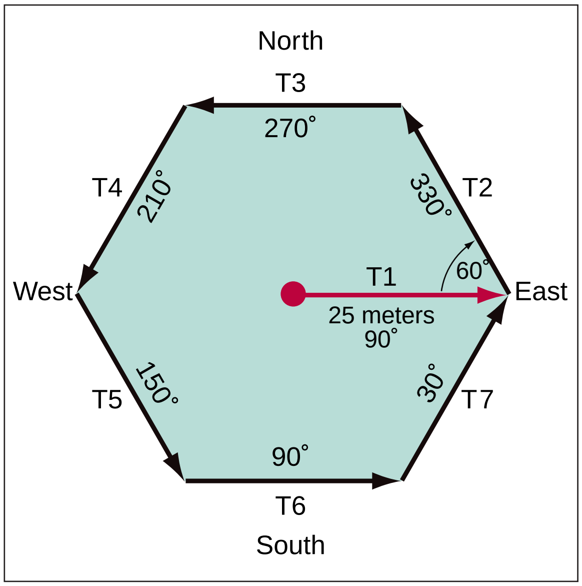
11. At the 25-meter mark, repeat steps 8 and 9.

After you get to the 25-meter mark and have measured transect slope, tallied all the woody intersects, estimated dead and live shrub and herbaceous height and cover, and measured total litter/duff depth and duff depth at the 15- and 25-meter marks, the transect is finished. You can reach down and pull on the tape to dislodge the nail at the zero end of the transect. Don't worry about disturbing the fuel bed at the end of the tape because the next transect, offset at 60 degrees from this transect, will again start at the 5 meter mark. Always check and make sure that you have recorded all the data for the transect in your *Fire Fuel Transect Measurements Data Sheet* before dislodging the tape. The slope of the transect is almost always the one measurement people forget to write down, so check to make sure you have measured and recorded the transect slope.

Part 5: Repeat measurements along next transect

12. The next transect (transect number 2 on your plot sheet) is established at a 60˚ angle from the first transect at an azimuth of 330˚ (Figure FF-6). Repeat steps 1 through 11. An azimuth of 270º is used for the third transect. Repeat steps 1 through 11. If after you measured fuels on the first three transects and there are less than 100 intersections for all wood classes combined (0 –1 cm, 1 – 3 cm, 3— 8 cm, and 8+ cm), then take additional transects in the order and direction shown in Figure FF-6 going counter-clockwise around the center of the plot. Stop taking measurements after 100 intersects are counted for all size classes combined. However, the entire transect must be finished even if you reach a 100 midway through a transect. Measure at least three transects to get 100 intersections for all fuel size classes, but no more than 7 transects. If you still haven't counted 100 intersections by transect number seven, stop after completing transect 7.

Figure FF-6: Direction and Distances for Each Fuel Transect Established in a Stand



Frequently Asked Questions

1. Why do we have to measure both live and dead herbaceous plants?

The distinction between live and dead herbaceous is somewhat arbitrary because it is highly dependent on phenology and season of sampling. After all, most herbaceous plants will eventually be dead by the end of the growing season, so why distinguish between the two? This is done to reference phenological conditions at your site. Since you recorded the date, these data will help fire modelers create fire danger models that predict phenology of the herbaceous material over the course of the year.

2. If it is difficult to distinguish between litter and duff, why try?

Litter and duff burn differently. Litter is generally consumed by flaming combustion while the duff is composed by smoldering combustion. This is because the moisture content and types of material that can be burned are different.

Acceptable Measurement Errors

1, 10, hour fuels	± 3 intersections of 100 intersections
100, 1000 hour fuels	± 1 intersections out of 100 intersections
1000 log diameters	± 2 cm
1000 log rot class	± 1 class
Live and dead herbaceous cover	± 5 percent cover
Live and dead shrub cover	± 5 percent cover
Duff and litter depth	± 0.5 cm
Percent litter that is duff	± 5 percent
Crown height	± 0.1 meter < 2 meters tall, ± 0.5 meter > 2 meters tall
Stand height	± 2 meters > 15 meters tall, ±0.1 meters < 15 meters tall
Canopy closure	± 5 percent
GPS coordinates	± 0.001 decimal degrees, ± 10 meters UTM coordinates
Slope	± 3 percent
Aspect	± 5 degrees
Elevation	± 30 meters

3. We have a homogeneous land cover site, but it looks like the woody material is not evenly spread out. What should we do?

Pick a place that best represents the conditions in the stand based on the vegetation (species composition, plant structure, plant size, canopy closure), the stand's history (stumps, burned logs, fire scars), ground (fuel loadings, duff depths), and most importantly, topography (slope, aspect, elevation). If there is variability, then you may want to sample multiple plots within the stand to capture the entire range of variation.

4. What is the best way to estimate the average heights of the dominant stratum and base of crowns in the lowest stratum?

If the trees or shrubs you measured for the canopy or in the dominant stratum, then you can average those measurements of heights. If not, you can either estimate the average height by looking at your site without taking any measurements, or take additional tree or shrub height measurements to calculate an average. Take enough measurements so that you feel confident in the estimate of dominant stratum height and base of crown in the lowest stratum height.

Fire Fuel Protocol: Center Plot Measurements

Field Guide

Task

To describe the general characteristics of the Fire Fuel Site by performing the *Land Cover Sample Site* and *Biometry Protocols* in the *Land Cover/Biology Investigation* as well as measuring slope, aspect, and average stand and crown heights.

What You Need

- ❑ *Fire Fuel Center Plot Data Sheet*
- ❑ *GPS Data Sheet*
- ❑ *The Center Plot Fire Fuel Guide*
- ❑ *MUC Field Guide* or *MUC Glossary of Terms*
- ❑ *Data Sheets* and *Field Guides* for the *Land Cover Sample Site and Biometry Protocols* in the *Land Cover/Biology Investigation*
- ❑ GPS receiver
- ❑ Wooden stakes or flags
- ❑ Flexible tape measure, at least 30 meters
- ❑ Compass
- ❑ Clinometer
- ❑ Tree guides
- ❑ Meter stick
- ❑ Clipboard
- ❑ Pencils or pens
- ❑ Colorful flagging (optional)
- ❑ Camera

In the Field

1. Do the *Land Cover Sample Site* and *Biometry Protocols* in the Land Cover/Biology Investigation. Identify latitude, longitude and elevation using a GPS, take photos and identify the MUC class. Do the full set of biometry measurements: ground and canopy cover, tree and shrub heights, dominant and codominant tree and shrub species identification.
2. Measure the aspect of the site. Stand perpendicular to the slope of the site with your eyes facing uphill. Measure the direction with the compass (1-360 degrees). Be sure to enter the true not magnetic directions. An aspect value of zero is entered for flat stands with no slope. 360 degrees is used for true north.
3. Work with another student who is approximately your same height. Measure the angle of the slope of the site by aiming your clinometer downhill 25 meters away. Look through the straw of the clinometer and locate the eyes of the other student. Record the angle on the *Fire Fuel Transect Measurements Data Sheet*. If you are looking downhill, turn the clinometer around, locate the eyes of the other student and record angle. Then, look upslope and repeat the procedure. Record second slope value.
4. Estimate the height of the trees or shrubs in the dominant stratum greater than 2 meters. To be considered a tree or shrub stratum, there needs to be at least 10% canopy cover.
5. Measure the heights of the base of the crowns of trees or shrubs in the lowest stratum. To be considered a tree or shrub stratum, there needs to be at least 10% canopy cover. The trees or shrubs must be greater than 2 meters tall. Calculate the average height.
6. Record any comments that may be relevant to the fuels data.

Fire Fuel Protocol: Transect Measurements

Field Guide

Task

Multiple measurements will be taken:

1. Slopes of individual transects,
2. Counts of the different sizes of downed woody fuel types,
3. Diameters and rot classes of logs greater than 8 cm,
4. Canopy cover and heights of shrubs less than 2-meters tall,
5. Herbaceous cover, and
6. Depths of litter and duff.

What You Need

- ❑ *Fire Fuel Transect Measurements Data Sheet*
- ❑ Wooden stakes
- ❑ Flexible tape measure, at least 30 meters
- ❑ Compass
- ❑ Clinometer
- ❑ 0.5-0.65 cm wooden dowel
- ❑ 2.5 wooden dowel
- ❑ 2 clear rulers in mm
- ❑ Meter stick
- ❑ Garden trowel
- ❑ Clipboard
- ❑ Pencils or pens
- ❑ Colorful tape or flagging (optional)

In the Field

Part 1: Measurements taken between the 5-meter and 15-meter marks along a transect

1. From the center of the site, lay a flexible tape measure due East (90˚) for 30 meters. Keep the tape measure as tight and straight as possible.
2. If not already done, mark the 5- meter, 7-meter, 10-meter, 15-meter, and 25-meter distances with colorful tape or flagging.
3. Use a clinometer to measure the slope of the site. Pick two students of approximately the same height. One student stands at the start of the transect with the clinometer while the other student walks 25 meters away down the slope. The student with the clinometer sights the eye of the other student and records the angle.
4. Starting at the 5-meter mark, walk to the 7-meter mark. Count the 0-1 cm, 1-3 cm, 3-8 cm, and 8+ cm fuel particles that cross the sampling plane of the transect between the 5 and 7-meter section of the transect. The sample plane starts at the ground surface and extends exactly 2 meters directly vertical above the ground surface. The diameter of the fuel particle is determined exactly where the particle crosses the sampling plane from the zero end. Use the 0.5-0.65 cm and 2.5 dowels and ruler to estimate size categories.

5. Use the ruler to measure the diameter of the downed woody fuel with diameters greater than 8 cm. Measure the diameter where the log crosses the sampling plane and perpendicular to the long axis of the log. Record the log decay class of each log (see Table FF-2).
6. Continue walking to the 10-meter mark. Count all 3-8 cm and greater than 8 cm downed fuel particles. Use the ruler to measure the diameter of the downed woody fuel greater than 8 cm. Record the log decay class of each log greater than 8 cm.
7. Continue walking to the 15-meter mark. Only count the downed woody fuel greater than 8 cm in diameter. Measure the diameter and record rot class for each log.

Part 2: Measurements taken at the 15-meter mark

8. At the 15-meter mark, estimate the canopy cover of live shrubs less than 2-meters tall within a circle that has a 1-meter radius. Make sure the plants have woody stems. Use the cover classes shown in Table FF-3.
9. Use the meter stick to estimate the average height of the live shrubs. Measure to the nearest 10 cm.
10. Estimate the cover of the dead parts of the shrubs less than 2-meters tall within the circle. Do not add those shrub branches that are unattached and lying on the ground. Use the cover classes shown in Table FF-3.
11. Use the meter stick to estimate the height of the dead shrub layer. Measure to the nearest 10 cm.
12. Estimate the percent cover of live herbaceous plants within the circle. Use the cover classes shown in Table FF-3.
13. Estimate the height of the live herbaceous layer
14. Estimate the percent cover of dead herbaceous plants within the circle. Use the cover classes shown in Table FF-3.
15. Estimate the height of the dead herbaceous layer
16. Between 20 and 30 cm to the right (as you face the end of the transect) of the 15-meter mark, use a garden trowel to cut through the litter and duff to the mineral soil. Try not to compress the litter and duff layer. Place the ruler with 0 end next to the mineral soil. Measure the thickness of the entire litter/duff layer with the ruler. If no place is available to measure duff and litter, enter '0' for duff and litter depth on data sheet.
17. Measure the thickness of the duff layer.

Part 3: Measurements taken between the 15 and 25-meter marks

18. Walk to the 25-meter mark. Count the downed woody fuel greater than 8 cm in diameter. Measure the diameter and record log decay class for each log.

Part 4: Measurements taken at the 25-meter mark

19. Repeat steps 8-17 for the 25-meter mark. These are the same measurements taken at the 15-meter mark.

Part 5: Repeat measurements along next transect

20. At the end of the transect, point the compass in a 330˚ direction. Lay a flexible tape measure in the 330˚ direction for 30 meters. Keep the tape measure as tight and straight as possible.
21. Repeat steps 2-19.
22. At the end of the transect, point the compass in a 210˚ direction. Lay a flexible tape measure in the 210˚ direction for 30 meters. Keep the tape measure as tight and straight as possible.
23. Repeat steps 2-19.
24. A total of 100 fuel particles for all size classes combined is requested. If this has not been reached, then lay out another transect in the 150˚ and repeat steps 2-19. A total of 7 transects can be measured as shown in Figure 3.

References

Brown, J.K. 1971. *A planar intersect method for sampling fuel volume and surface area.* Forest Science 17(1):96-102.

Brown, J.K. 1974. *Handbook for inventorying downed woody material.* USDA Forest Service General Technical Report INT-16. 22 pages.

Brown, J.K. and P.J. Roussopoulos. 1974. *Eliminating biases in the planar intersect method for estimating volumes of small fuels.* Forest Science 20(4):350-356.

Van Wagner, C.E. 1968. *The line intersect method in forest fuel sampling.* Forest Science 14(1):20-31.

Glossary

Arboreal
Plants living in or on trees

Aspect
The general down slope direction the stand faces

Biota
All living things within an ecosystem

Biomass
Biologically derived organic material within an ecosystem. Biomass can be live (green biomass) and dead (necromass)

Downed, dead woody fuels
Dead woody fuels found on the ground. Dead fuels no longer manufacture food or circulate water so their moisture contents are more closely linked to atmospheric conditions. These are the most important for wildfire spread and the most influential for subsequent fire effects.

Duff
Composed of primarily decomposing organic matter. The duff is generally moist, heavy, dense, and dark.

Fire effects
The damage or influence a fire has on the biota

Fire intensity
The flame length

Fire severity
A term quantifying fire effects. Severity is the damage that heat from fire on living organisms above and below ground.

Fire spread
How fast a fire moves

Ha
Abbreviation for hectare or 10,000 square meters

Live fuels
Those biomass pools that are living plants extracting water from the soil

Litter
Composed of freshly deposited leaf, needle and other plant parts. Plant parts are readily identifiable in the litter.

Loading
The weight or mass of dead or live fuels per unit area (e.g., kg m^{-2})

Phenology
The study of recurring biological cycles and their connection to climate

Stand
An area of homogenous vegetation and fuel conditions usually delineated by the dominant vegetation type

Fire Fuel Protocol:

Center Plot Data Sheet

School Name: ____

Observer Names: ____

Date: ________________ Study Site Name (give your site a unique name): ________________

Aspect: ________________ degrees True North (enter 0 for sites with no slope)

Overall slope of stand: looking up __________slope degrees looking down __________slope degrees

Heights of trees or shrubs in dominant stratum:

Tree or Shrub	Height(m)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Average height of dominant stratum = (sum of heights) ÷ (total number of trees and shrubs)

Average height: ____________

Heights of the base of crowns in lowest stratum:

Tree or Shrub	Height(m)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Average height of base of crowns = (sum of heights) ÷ (total number of trees and shrubs)

Average height: ________

Comments: ____

____

____

Fire Fuel Protocol:

Transect Measurements Data Sheet

School Name: ____________________

Observer Names: ____________________

Date: __________ Study Site Name (give your site a unique name): __________

Number of Transects: __________

Woody Fuel Counts

	Transect 1	Transect 2	Transect 3	Transect 4
Direction of transect (True North)	90°	330°	270°	210°
Slope of transect (degrees)				
0-1 cm diameters (5-7 m mark)				
1-3 cm diameters (5-10 m mark)				
3-8 cm diameters (5-25 m mark)				

	Transect 5	Transect 6	Transect 7
Direction of transect (True North)	150°	90°	30°
Slope of transect (degrees)			
0-1 cm diameters (5-7 m mark)			
1-3 cm diameters (5-10 m mark)			
3-8 cm diameters (5-25 m mark)			

8+ cm Diameters and Log Decay Classes (between 5-25 m along transect)

LDC = Log Decay Class

Log	Transect 1	Transect 2	Transect 3	Transect 4
Azimuth (True North)	90°	330°	270°	210°
	Diameter (cm)/ LDC	Diameter (cm)/ LDC	Diameter (cm)/ LDC	Diameter (cm)/ LDC
1	/	/	/	/
2	/	/	/	/
3	/	/	/	/
4	/	/	/	/
5	/	/	/	/
6	/	/	/	/
7	/	/	/	/
8	/	/	/	/
9	/	/	/	/
10	/	/	/	/

Log	Transect 5	Transect 6	Transect 37
Azimuth (True North)	150°	90°	30°
	Diameter (cm)/ LDC	Diameter (cm)/ LDC	Diameter (cm)/ LDC
1	/	/	/
2	/	/	/
3	/	/	/
4	/	/	/
5	/	/	/
6	/	/	/
7	/	/	/
8	/	/	/
9	/	/	/
10	/	/	/

LDC-Log Decay Classes

1 = sound, needles intact (green or brown)
2 = sound, bark and branches present
3 = sound, bark partially intact, branches gone
4 = rotten, bark and branches gone
5 = rotten, more than half the log diameter above soil surface

Summary of 8 +cm logs

	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 7
Total 8+ cm logs							
Total rot class 1 logs							
Total rot class 2 logs							
Total rot class 3 logs							
Total rot class 4 logs							
Total rot class 5 logs							

Shrub - Dead and Live Cover and Height Estimates at 15 m and 25 m Mark

	Transect 1	Transect 2	Transect 3	Transect 4
Azimuth (True North)	90°	330°	270°	210°
	Live / Dead	Live / Dead	Live / Dead	Live / Dead
Cover 15 m mark Canopy Cover Class	/	/	/	/
Height 15 m mark (cm)	/	/	/	/
Cover 25 m mark Canopy Cover Class	/	/	/	/
Height 25 m mark (cm)	/	/	/	/

	Transect 5	Transect 6	Transect 7
Azimuth (True North)	150°	90°	30°
	Live / Dead	Live / Dead	Live / Dead
Cover 15 m mark Canopy Cover Class	/	/	/
Height 15 m mark (cm)	/	/	/
Cover 25 m mark Canopy Cover Class	/	/	/
Height 25 m mark (cm)	/	/	/

Cover Class	Percent
01	Less than 1 %
03	1 to 5%
10	5 to 15%
20	15 to 25%
30	25 to 35%
40	35 to 45%
50	45 to 55%
60	55 to 65%
70	65 to 75%
80	75 to 85%
90	85 to 95%
99	95 to 100%

Herbaceous - Dead and Live Cover and Height Estimates at 15 m and 25 m Mark

	Transect 1	Transect 2	Transect 3	Transect 4
Azimuth (True North)	90°	330°	270°	210°
	Live / Dead	Live / Dead	Live / Dead	Live / Dead
Cover 15 m mark Canopy Cover Class	/	/	/	/
Height 15 m mark (cm)	/	/	/	/
Cover 25 m mark Canopy Cover Class	/	/	/	/
Height 25 m mark (cm)	/	/	/	/

	Transect 5	Transect 6	Transect 7
Azimuth (True North)	150°	90°	30°
	Live / Dead	Live / Dead	Live / Dead
Cover 15 m mark Canopy Cover Class	/	/	/
Height 15 m mark (cm)	/	/	/
Cover 25 m mark Canopy Cover Class	/	/	/
Height 25 m mark (cm)	/	/	/

Duff and Litter - Depth Measurements in Centimeters at 15 m and 25 m Mark

	Transect 1	Transect 2	Transect 3	Transect 4
Azimuth (True North)	90°	330°	270°	210°
	Total Depth/ Duff Depth	Total Depth/ Duff Depth	Total Depth/ Duff Depth	Total Depth/ Duff Depth
15 m mark (cm)	/	/	/	/
25 m mark (cm)	/	/	/	/

	Transect 5	Transect 6	Transect 7
Azimuth (True North)	150°	90°	30°
	Total Depth/ Duff Depth	Total Depth/ Duff Depth	Total Depth/ Duff Depth
15 m mark (cm)	/	/	/
25 m mark (cm)	/	/	/

Table FF-3: Fuel Types and Size Classes Used in Fire Management. The classes of fuels used in this protocol. The diameters of the downed wood are often referred to the average length of time it takes to dry the wood.

Fuel Type	Size (twig, branch, or trunk diameter)	Description
Crown Foliage	Any	Living and dead crown foliage including needles and broad leaves
Crown Branchwood	0 to 3 cm	Live and dead crown woody branches
Shrub — Live	Any	Living woody plants – trees and shrubs less than 2 meters tall
Shrub — Dead	Any	Dead shrubby material suspended above ground. This includes trees and shrubs less than 2 meters tall.
Herbaceous - Live	Any	Live herbaceous plants including grasses, sedges, forbs, ferns, and lichen
Herbaceous — Dead	Any	Dead herbaceous plant parts above ground
Litter	None	Recently fallen needles, leaves, cones, and bark
Duff	None	Partially decomposed organic material below the litter layer
Downed Woody	0 to 1 cm	Takes 1 hour to dry woody twigs and branches
	1 to 3 cm	Takes 10 hours to dry woody twigs and branches
	3 to 8 cm	Takes 100 hours to dry woody branches
	8 + cm	Takes 1000 or more hours to dry branches and logs

Learning Activities

*Getting to Know Your Satellite Imagery and GLOBE Study Site**
Students use the satellite image of their GLOBE Study Site to become familiar with the different types of land cover in their area.

*Site Seeing**
Beginning and intermediate level activities introduce students to the concept of dynamic systems.

*Leaf Classification**
Students make a collection of leaves and then discover how a hierarchical classification system is developed by sorting and organizing their leaves according to a set of labels and rules which they specify.

*Odyssey of the Eyes**
These beginning, intermediate and advanced level activities will introduce students to remote sensing and mapping.

*Bird Beak Accuracy Assessment**
Students learn how to evaluate the accuracy of a classification they perform.

*Discovery Area**
Students use the satellite image of the GLOBE Study Site and their knowledge of remote sensing to decide where a new hospital should be located.

*Using GLOBE Data to Analyze Land Cover**
Students find another GLOBE school that reported the same MUC class and systematically compare the other GLOBE measurements that they each reported.

* See the full e-guide version of the *Teacher's Guide* available on the GLOBE Web site and CD-ROM.

Getting to Know Your Satellite Imagery and GLOBE Study Site

Purpose

To introduce students to the Landsat TM images of the GLOBE Study Site, the iterative nature of mapping and how to identify land cover types in images

Overview

Students outline and label areas in their school's Landsat TM image to create a simple land cover map. They use this map to locate areas for field study.

Student Outcomes

Science Concepts

Geography

How to use maps (real and imaginary)

The physical characteristics of place

The characteristics and distribution of ecosystems

Scientific Inquiry Abilities

Use maps, aerial photographs and other tools and techniques on order to create a land cove map.

Recognize and analyze differing viewpoints on land cover classification and reach a consensus.

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate procedures, descriptions, and predictions.

Level

All

Time

One to two class periods for the initial mapping

Materials and Tools

Hard-copy Landsat TM images of the 15 km x 15 km GLOBE Study Site, true-color and false-color infrared

Clear plastic sheet(s)

Fine point markers

Road maps and topographic maps, if available

Aerial photographs, if available

Preparation

Print or make color copies of the satellite image.

As a demonstration, copy the example maps to transparency film and use them to illustrate the process.

Prerequisites

Students need only be familiar with the area in their GLOBE Study Site.

Background

The Landsat Thematic Mapper (TM) image of a school's GLOBE Study Site can be used to identify land cover types once students understand what the colors on the different printed images represent. (For more information, see the *Manual Classification Tutorial*.)

In the "true-color" image, which represents the surface of the Earth approximately as we would see it from space, vegetation ranges from light green to very dark green, sometimes appearing almost black. Water is blue to black unless it is carrying suspended sediments when it can appear gray to green. Exposed mineral material (rocks, sand, buildings) is white to purple. This image is good for identifying developed areas and areas of exposed rock and sand. It does not clearly distinguish specific vegetation types, or between dark vegetation and water.

In the "false-color infrared" image, which mimics an aerial infrared photograph, red hues are associated with live vegetation. Very bright shades indicate vigorously growing vegetation. For example, a grassy area might show as a bright pink color, whereas a dense stand of coniferous trees would appear as a very dark red. Intermediate shades can represent deciduous and mixed deciduous/coniferous trees. As a very general rule, "the brighter the red, the shorter the vegetation." Senescent, or "dead" vegetation is shades of green or tan. In this view, water is almost always black and mineral material, including buildings, rock, sand, and bare soil, appear in shades of blue, purple and white.

What To Do and How To Do It

1. Review the process students will carry out using the illustrations accompanying this exercise. They show the development of a student map for the Beverly, MA satellite image. Figure LAND-SS-2 shows the Beverly image in false-color infrared, this is the satellite image to use as the base layer.

   Step 1: Water bodies are outlined and labeled.

   Step 2: Elements of the area's transportation system are outlined and labeled. (The labels from the previous diagram have been eliminated for the sake of clarity.)

   Step 3: Residential and commercially developed areas are outlined and labeled.

   Step 4: Some vegetated areas, a golf course, beaches, and some "unknown" areas are outlined and labeled.

   Step 5: The final land cover type map with all areas outlined and labeled.
2. Place the plastic overlay on top of the school's printed image and mark the corners of the image. This will help to realign the overlay if it moves.
3. Using a fine point marker, outline areas that represent homogeneous land cover types, and label them appropriately (forest, field, urban, etc.).
4. Outline areas of land cover that the class is not sure of. Ask students to suggest ways they can make an educated guess about the land cover in these areas. Use road maps, topographic maps and aerial photos, if available, to assist you. Recruit students who live near these areas to try to identify them.

The number of land cover types students identify will depend on a school's geographic location. In heavily urban areas, students may be able to identify only a few types, as most developed land cover types appear similar in both satellite images. This is because these land cover types are highly reflective and thus appear bright in the images. In areas where there is a variety of land cover types, including natural vegetation, cultivated and developed areas, there may be more discernible land cover types, but many small areas may make identification difficult.

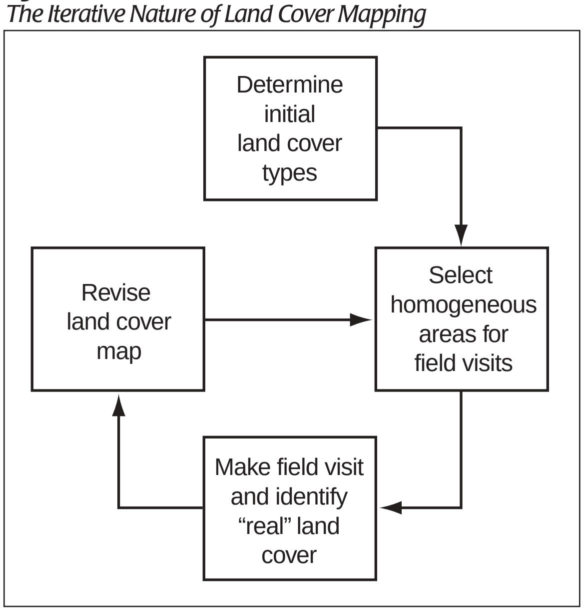
How can we identify land cover types in unknown areas?

Using the overlays, locate areas that appear to have uniform land cover and seem to measure at least 90 m x 90 m (3 pixels x 3 pixels) in size. These are potential Land Cover Sample Sites, which can now be visited.

The Job Is Not Done!

The map is only the first step in a "cyclic" process. Usually, some of the areas identified are "guesses" and there are areas for which the land cover type is unknown. The next step is to visit these areas to validate their land cover type. After visiting an area and determining its real land cover, return to the map and either correct it or update it. Return to the field to visit more areas, and continue the process of correcting and updating the land cover type map. Such a process is called "iterative," and each new map represents a new "iteration" in the process. Figure LAND-SS-1 represents this process.

Figure LAND-SS-1:
The Iterative Nature of Land Cover Mapping

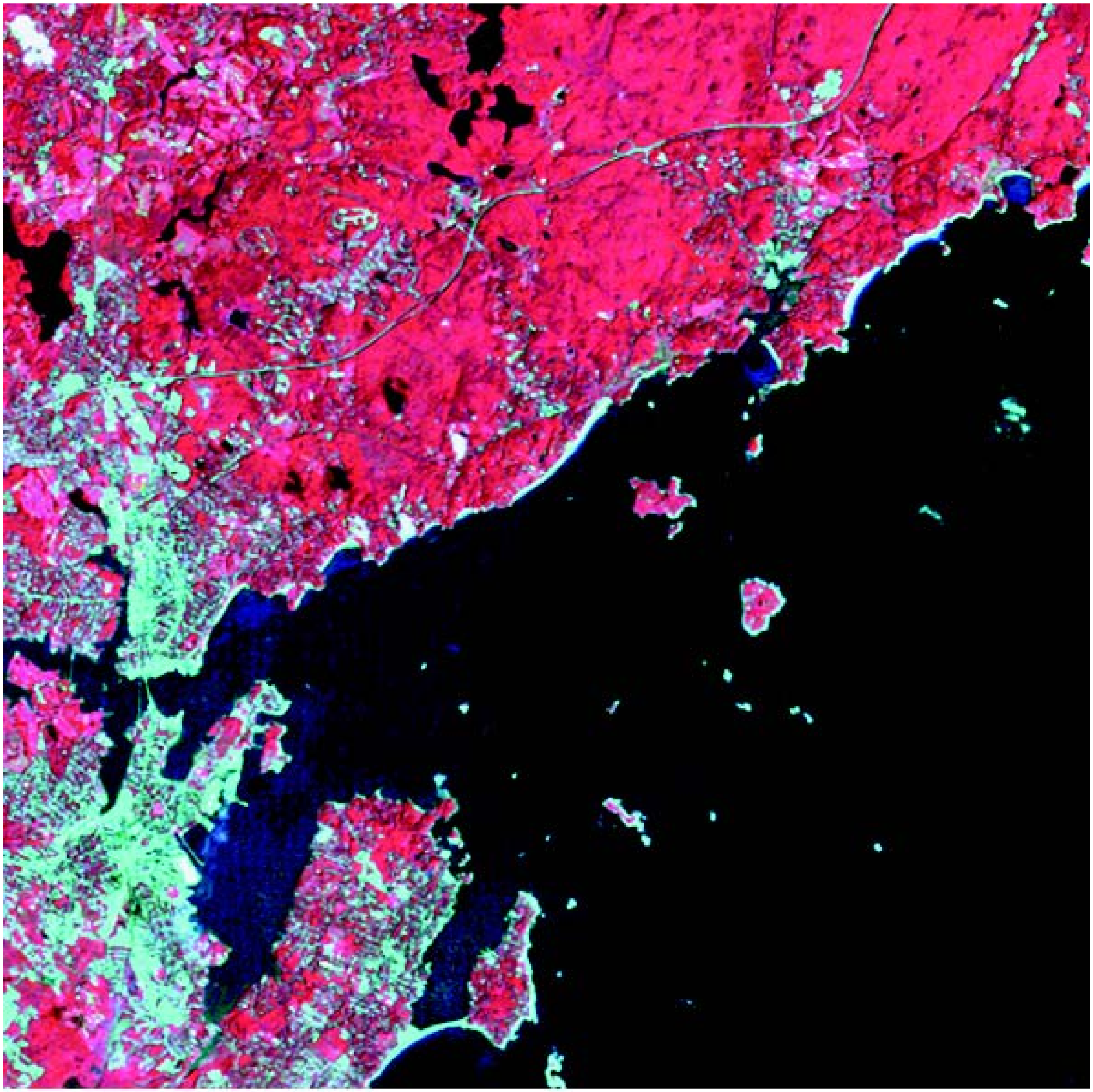


Assessment

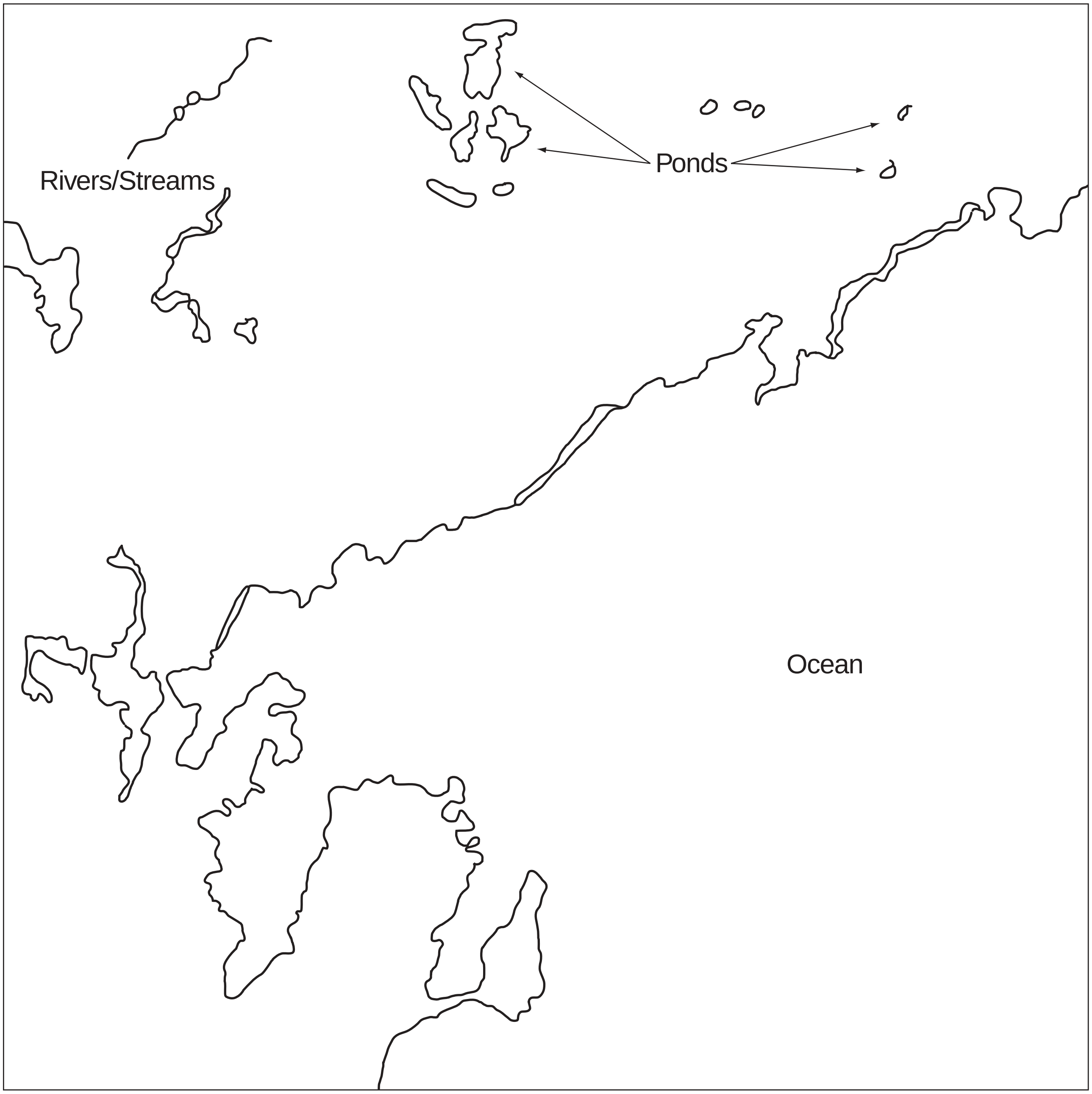
Assess students' understanding of the mapping process by asking them to explain both what they did and why they did it. Some leading questions might include:

- How many different land cover types were you able to distinguish in the satellite images?
- Which land cover types are <u>easiest</u> to identify in the true-color image? In the false-color infrared image? Why do you think this is the case?
- What land cover types that exist on the ground do you think are <u>difficult</u> to identify on the satellite images?
- If you live in coastal or estuarine areas, how would the position of the tides (high or low) affect your land cover mapping?
- How would the time of year your satellite image was acquired affect land cover mapping in your part of the world?
- What other conditions at the time your image was acquired might influence your land cover mapping? (Clue: In the Beverly, MA, image, the "unknown areas," which show both white and black, are small cumulus clouds and their shadows!)
- Consider when the satellite image was acquired. What has changed in the satellite image since then?
- TM images are always acquired in the morning. If you live in a mountainous area, how will this effect what you see in the image? Where will the shadows of hills and mountains be?

Figure LAND-SS-2: Beverly, MA, in false-color infrared

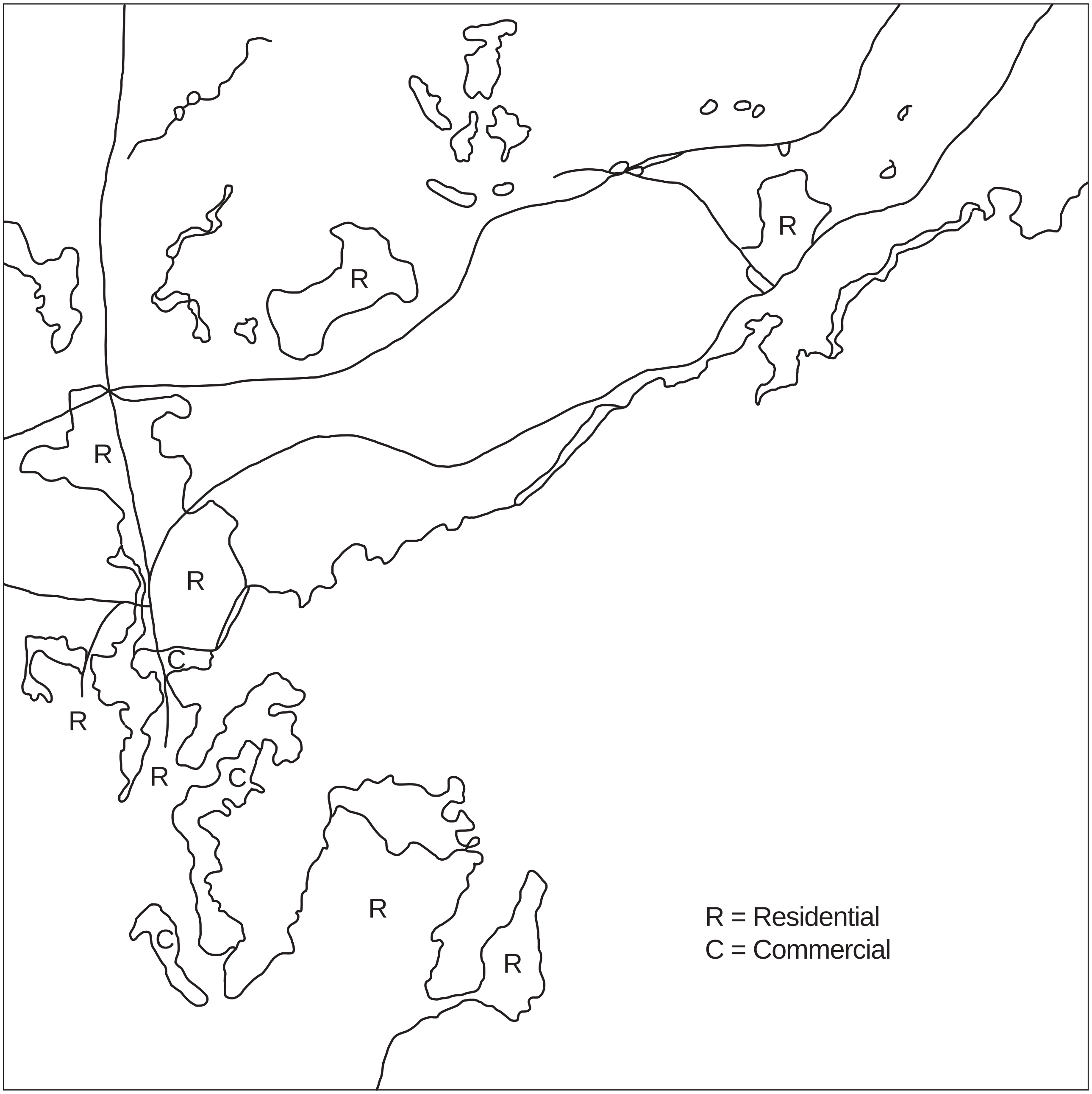


Step 1: Water Bodies are Identified

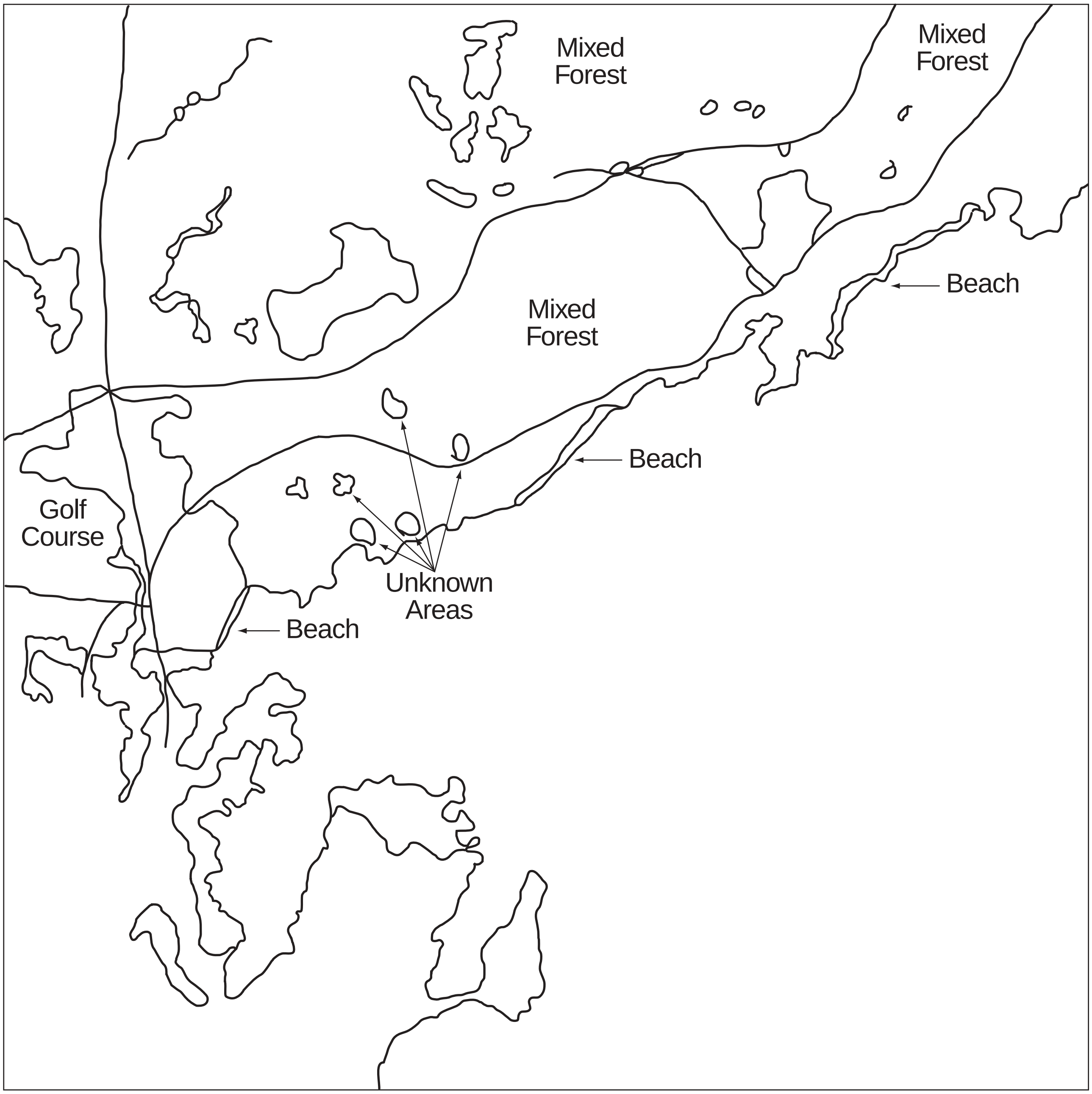


Step 2: Transportation Features are Added

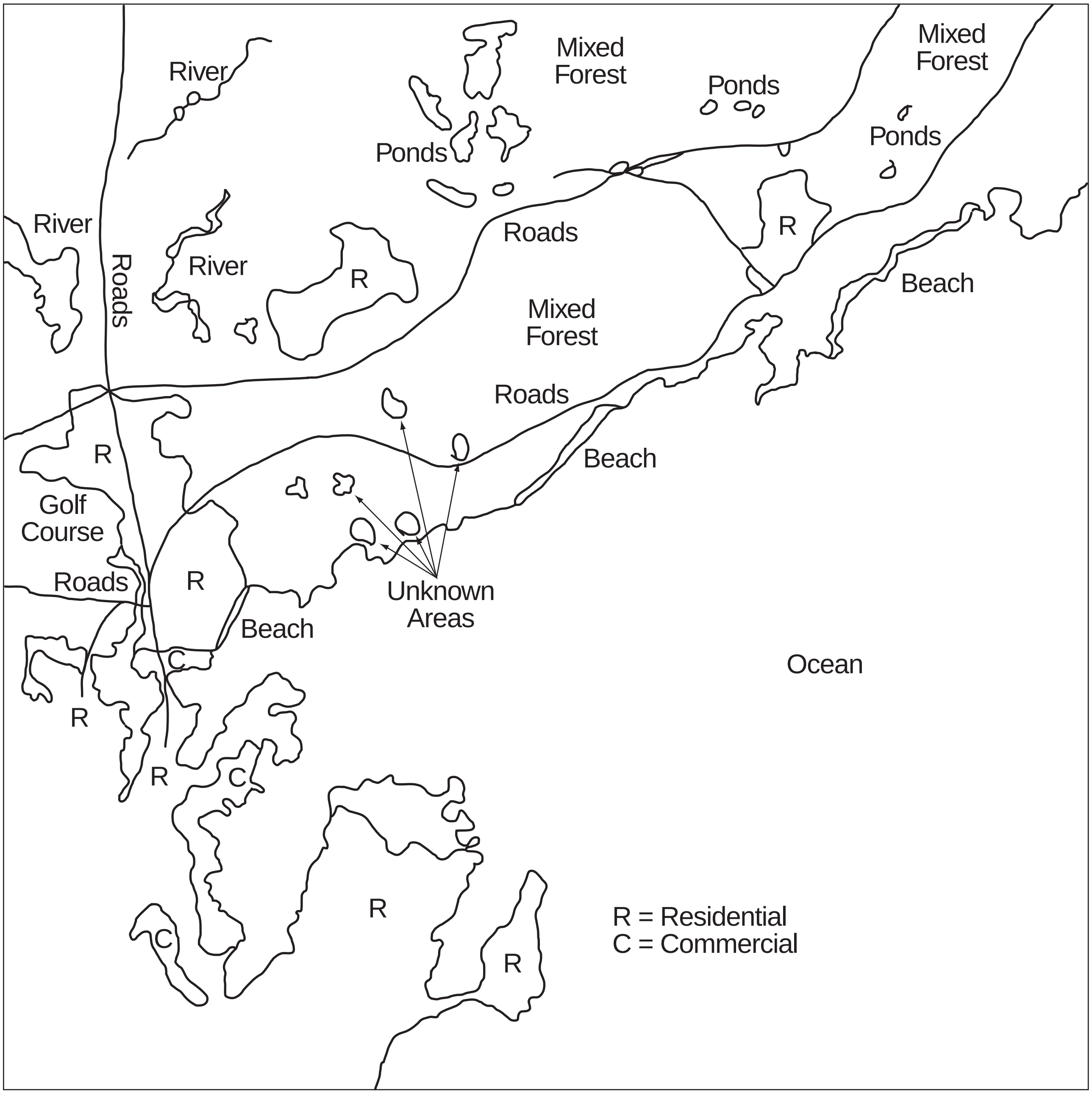
Step 3: Buildings and Developed Areas are Added



Step 4: Vegetated Areas and Other Features are Added



Step 5: A Student Land Cover Map



Site Seeing
Beginning Level

Site Seeing Learning Activities

These pre-protocol activities introduce students to the concept of a system. The students will explore different scales of the system, identify the components, and try to determine their relationship to each other. The concept of a system will help students understand why they are conducting biometry measurements.

Purpose

To help students determine that a system's boundaries are based upon the question(s) a scientist wants to answer

Overview

Students will investigate the center pixel of a homogeneous 90 m x 90 m Land Cover Sample Site. The students will use simple observational techniques. The intention is for students to become familiar with their system.

Student Outcomes

Science Content

Physical Science

Objects have observable physical properties.

People can often learn about things around them by just observing.

Describing things as accurately as possible is important.

Life Science

Each plant has different structures but some plants are alike in the way they look.

Plants have features that help them live in different environments.

Science and Technology

People have always had questions about their world. Science is one way of answering questions.

Scientists in different disciplines ask different questions, use different methods of investigation.

Science as Inquiry

Scientists conduct investigations for a variety of reasons.

Geography

Primary

The physical characteristics of places

Middle

Physical characteristics of places

The distribution of major physical features at different scales

Enrichment

A homogeneous 90 m x 90 m Land Cover Sample Site can be considered a system.

Your system includes components such as plants, water, soil, rocks, and animals.

Your system has inputs such as solar energy, water, carbon dioxide, oxygen, and dust.

Your system has outputs such as water, carbon dioxide, oxygen, heat, and waste products.

Scientific Inquiry Abilities

Draw pictures that correctly portray at least some of the features of the thing being described.

Propose answers to questions about the system described.

Level

Primary

Time

Two or three class periods

Materials and Tools

Paper (regular size and cut to specific sizes, see *Preparation*)

Colored pencils or crayons

Compasses

Camera

String (pre-measured)
Ruler and/or Tape measure
Containers to hold soil samples

Preparation

Cut two different sizes of paper for each student – one approximately 11 cm x 11 cm and one 5 cm x 5 cm.

The center pixel of a natural homogeneous Land Cover Sample Site should be laid out.

Prerequisites

Students should know how to use a compass and how to pace (See *Investigation Instruments)*.

Introduction to Systems and Scale

A *system* is any collection of interacting "things" that have some influence on one another and appear to operate as a unified whole. The "things" can be almost anything, including objects, organisms, machines, ideas, numbers, or organizations. Scientists investigate natural systems for a variety of reasons. The question a scientist wants to answer often determines how the boundaries of the system are defined. See Figure LAND-SB-1. The example below depicts the relative scale a scientist might want to use to answer different questions. These studies would consider completely different factors determined by the system's scale.

When we repeat biometry measurements every year in the same Land Cover Sample Site, we are looking at a certain system to see if we can detect changes over time. These may include the growth of trees and changes in the amount of canopy and ground cover. By collecting data over many years, we can see if the data are consistent over time or if there is variation. To understand the data, students need to be familiar with the variety of factors affecting a system. If they know what is coming in and out of the system and the basic relationships of the components within the system, they will be able to see patterns that will help them make generalizations and predictions. For example, water comes into a forested system in the form of rain. Some of the water is stored in the trees and is used in growth. Some is released into the atmosphere. Some stays on the surface. Some percolates into the ground and replenishes the water table.

Data variation could indicate changes in either the input, output, or the cycles that process matter and energy. In a series of drought years, the growth of the trees may be stunted due to the lack of water, stress, production, or fitness. Consistent temperature rises could cause a longer growing season resulting in an increase in production. This may be evident in leaves being on the trees longer or the trees increasing in size more during those years, as

Figure LAND-SB-1: Using Questions to Determine System Boundaries

A scientist might want to study an entire ecosystem type such as wetlands to determine the amount of acreage still left in the world.

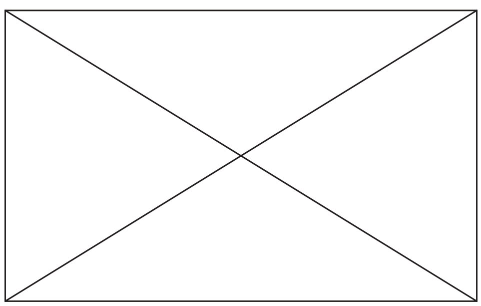
Alternatively, a scientist may be interested in a specific wetland plant community so he or she can experiment with different restoration techniques.

Or, a scientist might want to study one type of wetland plant to determine the plant's sensitivity to certain kinds of pollution.

seen in the circumference or tree height. The data your class collects will help your students and the GLOBE scientists understand the system around them.

What To Do and How To Do It

1. Have students close their eyes and imagine their perfect place in the whole world (e.g. beach forest, next to a campfire, in a candy store). Give them a minute to imagine this image. Have them draw their special place on a piece of paper. How many of the students imagined a natural area for their special place?
2. On the other side of the piece of paper, have students draw two diagonals that intersect in the center. This should form four triangles. This paper will be used in Step 4.



3. Visit the center pixel of a 90 m x 90 m natural Land Cover Sample Site. Ask the students to answer the following questions.
   a. What do you see, smell, feel, and hear?
   b. Is it wet/dry, warm/cool?
   c. Is there a lot of sunlight hitting the ground?
   d. What living things do you see? Can you name some?
   e. What non-living things do you see? Are they natural or man-made?
   f. How might your system change in the different seasons?
4. Staying in the center pixel of the site, ask the students to draw each boundary on the divided paper – one triangle for each boundary/view – North, South, East, and West. These will be side views. Encourage them to be observant and draw details.
5. From the center point, take a picture of each directional view. (Be sure to record the exposure number.) Once the pictures are developed, have the students compare their sketched views with the photographs. Have they drawn enough detail in their sketches to identify which picture corresponds with each compass direction? Are there parts of the system that they missed?
6. In order to obtain an increased knowledge of the natural Land Cover Sample Site, have students lay out on the ground a 30 m x 30 m square made of string. Have them draw what they observe on the 11 cm x 11 cm piece of paper.
7. Have them answer questions a through f from Step 3. How did changing the boundaries change what they saw?
8. Have the students take a soil sample from their individual plots with an auger, trowel, or shovel. Try to get at least 15 cm down into the soil and place it in the soil container.
9. In the classroom, have the students observe the soil. Have the students draw what they see on the 5 cm x 5 cm piece of paper. Now what parts do you see? Are there living things here or parts of living things?
10. On a flat surface, ask the students to put the largest piece of paper down first (Land Cover Sample Site Sketch), place the medium-sized paper on top (30 m x 30 m square sketch) and the smallest piece of paper (soil sketch) on top of that. Ask students the following questions:
    a. What questions could you answer better when you looked at the 30 m x 30 m square (or system)?
    b. What questions could you answer better when you looked at the soil sample rather than the entire Land Cover Sample Site?
    c. How did changing the boundaries

change what you observe?

Discussion Questions

1. If something happens in your neighbor's 30 m x 30 m square, how do you think it affects your square?
2. What is above your 30 m x 30 m square? What is below it?
3. Does what is above and below affect your square in any way? How?
4. What enters and leaves your system? (sunlight, water, seeds, nuts, animals, etc.)

Site Seeing
Intermediate Level

Site Seeing Learning Activities

These pre-protocol activities introduce students to the concept of a system. The students will explore different scales of the system, identify the components, and try to determine their relationship to each other. The concept of a system will help students understand why they are conducting the biometry measurements.

Purpose

To investigate the idea that every dynamic system has energy and matter in several different forms. Inputs and outputs will vary depending upon the physical components of the site, the plant and animal life, the determined boundaries or scale of the study and the season.

Overview

The class will travel to several different Land Cover Sample Sites. At each site, students will explore a larger variety of system inputs and outputs, and will use more complex methods of data acquisition and analysis. The students will use the data from each site to compare and contrast the inputs and outputs of the environments. The intermediate level of Site Seeing builds upon the concepts presented in the beginning level.

Student Outcomes

Science Concepts

Life Science

Earth has many different environments that support different combinations of organisms.

All populations living together and the physical factors with which they interact constitute and ecosystem.

Humans can change ecosystem balance.

Geography

How to use maps (real and imaginary)

The physical characteristics of place

The characteristics and spatial distribution of ecosystems

How humans modify the environment

Scientific Inquiry Abilities

Integrate data from variety of different data sets to gain dynamic understanding of how Earth system works.

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate procedures, descriptions, and predictions.

Level

Middle

Time

Three class periods or a field trip with one class period of follow-up

Materials and Tools

Thermometers

Rain gauges

Site Seeing Field Data Work Sheet

Beaufort Scale Work Sheet

Heavy paper cup

Paper

Preparation

Arrange for parents or other volunteers to accompany students to the sites.

Divide the class into teams as necessary. Ideally, each team would work on a different site but it may be more realistic to have groups working on the tasks in a different order so they can share equipment.

Prerequisites

The beginning activity is recommended. If not used, students should understand the concept of system boundaries.

What To Do and How To Do It

Collect the data listed below at three different sites within your GLOBE Study Site. The sites should include an open place such as a field or playground, a site near open water, and a naturally vegetated Land Cover Sample Site (Closed Forest, Woodland, Shrubland, or Herbaceous Vegetation). Plan to visit the sites on the same day or on different days at about the same time.

1. **Temperature –** Measure the site's temperature 0.5 m above the ground, at ground level and 5.0 cm deep in the soil. See the *Soil Protocols* for more details. To get the temperature at or above ground level, you should insert the thermometer through a hole in the bottom of an upside-down heavy paper cup. The cup acts as a shield around the tip of the thermometer so that direct sunlight and other extraneous sources of heat do not cause inaccurate readings. The thermometer should remain in one location until the temperature does not vary for 1-2 minutes. To get the temperature of the soil below ground, carefully insert the tip of the thermometer 2.5 cm into the ground.
2. **Precipitation–** Determine the amount of rainfall for the last growing season. If you do not conduct the *GLOBE Precipitation Protocol,* you can obtain the information from a local meteorologist or through the GLOBE Web site links. Has it rained lately? What evidence is there – a lake, streams, water retainment areas, puddles?
3. **Sunlight –** When the sun is shining, look around the site for signs of sunlight on the trees, shrubs and on the ground. How much sunlight reaches the top of the trees? How much is reaching the ground? If the plants are absorbing sunlight, what happens to the sunlight? Is it being reflected (that means the leaves would be shiny like aluminum foil)?

Note: Many younger students will think that plants get their food from the soil and will not think the sun is used to make food during photosynthesis. They will think that sun helps plants to grow, but are not sure how or why. Question students on how plants use sunlight in their life cycle. As an extension, paperclip a small piece of paper on a leaf for a couple days to see what happens to it.

4. **Wind –** How strong is the wind blowing in the site? Use the *Beaufort Scale Work Sheet* to measure the wind speed. Are the leaves or grasses shaking in the breeze? Is the wind strong enough to bend small branches or flattened grasses? Large branches? Use a piece of paper as a temporary windsock. One student can hold the paper away from the body, while the others observe whether it hangs straight down or blows out at an angle. Use a compass to determine from which direction the wind seems to be blowing.
5. **Animal Life –** Note and record the various kinds of animals at the site (insects, birds, reptiles, fish, amphibians, mammals). Record evidence of animals such as scat, tracks, burrows, or chewed leaves. Which is the most dominant?
6. **Plant Life –** Observe the various types of plants at the site (large trees, small trees, shrubs, small plants, grasses). Record the

most common types of plants found in the site. Which is the most dominant?

7. Report your findings and share what you have learned as your teacher instructs.

After listening to each other's reports, the class can complete a large composite class chart. Use this composite chart as a basis for discussing differences between the locations and interactions the students observe among the various elements.

Discussion Questions

1. Which site had the highest air temperature? The lowest? The most wind? The least wind?
2. What relationship does light seem to have with air temperature? With soil moisture? With plants?
3. How do the various sites differ in numbers or diversity of species of animals and plants? How are they similar?
4. Which sites showed the greatest seasonal variations in the parameters you measured? Why should this be so?
5. Which of the six variables studied seems most important for determining the character of the environment at each site? What makes you think so?
6. What are the inputs to the various systems? Which factors are outputs? Which of the six measured elements stays within the system? Draw a picture or a flow chart depicting this.
7. Have students draw diagrams of their systems or make up a story about their system tracing the path of solar energy through the system.

Further Investigations and Ideas for Assessment

1. Visit the sites selected again at different seasons and repeat the investigation. How have the various factors changed? What factors influenced the change? If you have deciduous trees, what factors might have influenced the leaf on or leaf off process during the course of the year?
2. Have students construct terrariums. Try to make the terrarium more like one of your system sites. Try to model your system based upon the data you collected in this learning activity. Add wind, moderate the temperature and/or water, allow the appropriate amount of sunlight, add plants, and mimic animal effects. Try for seasonal variations. Can you do it? What limitations are there to the models? Can you develop the same cycles that exist in nature between the living and nonliving factors?

Table LAND-SI-1: Beaufort Scale

Wind Speed kmph	Wind Speed mph	Beaufort Number	Wind Description	Observed Effects on Land
<1	<1	0	Calm	Calm, no movement of leaves
1–3	1–3	1	Light air	Slight leaf movement, smoke drifts, wind vanes moving
6–11	4–7	2	Light breeze	Leaves rustling, wind felt, wind vanes moving
12–19	8–12	3	Gentle breeze	Leaves and twigs in motion, small flags and banners extended
20–29	13–18	4	Moderate breeze	Small branches moving; raising dust, paper litter, and dry leaves
30–38	19–24	5	Fresh breeze	Small trees and branches swaying, wavelets forming on inland water ways
39–49	25–31	6	Strong breeze	Large branches swaying, overhead wires whistling, difficult to control an umbrella
50–61	32–38	7	Moderate gale	Entire trees moving, difficult of walk into wind
62–74	39–46	8	Fresh gale	Small branches breaking, difficult to walk, moving automobiles drifting and veering
75–87	47–54	9	Strong gale	Roof shingles blown away, slight damage to structures, broken branches littering the ground
88–101	55-63	10	Whole gale	Uprooted and broken trees, structural damage
102–116	64–73	11	Storm	Widespread damage to structures and trees, a rare occurrence
>117	>74	12–17	Hurricane	Severe to catastrophic damage

Site Seeing

Field Data Work Sheet

Name(s): ______________________________ **Date:** ____________

______________________________ **Time:** ____________

Type of Site (circle one): Open Field Site Near Water Land Cover Sample Site

System Component	Data
Temperature - 0.5 m above ground - at ground level - at 2.5 cm deep in the soil	
Precipitation - amount - rain lately? - evidence	
Sunlight - reaches top of trees - reaches the ground - what happens to sunlight?	
Wind - Beaufort scale # - strength - direction	
Animal Life - kinds - evidence - most dominant?	
Plant Life - types - most dominant?	

Other observations (Metadata) and drawings:

Leaf Classification

Purpose

To develop a classification system for a set of objects, learn about hierarchical classification systems, build skills for using the MUC System

Overview

As a group, students will develop their own classification system for sorting leaves and will learn that there are different ways to classify the same group of objects. This activity introduces the complexity of a "simple" task for which there are no absolutely correct answers.

Student Outcomes

Science Concepts

Physical Science

Objects have observable properties that can be measured using tools.

Objects have observable properties.

Scientific Inquiry Abilities

Classification helps organize and understand the natural world.

A classification system is a system of labels and rules used to sort objects.

A hierarchical system has multiple levels of increasing detail.

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate procedures, descriptions, and predictions.

Level

All

Time

One class period

Materials and Tools

A variety of different leaves

Chalk board or large paper for classification system outline

Preparation

Collect a variety of different leaves. (If time allows, take students outside to collect leaves or ask each student to bring in 3-5 different kinds of leaves and needles.)

Prerequisites

None

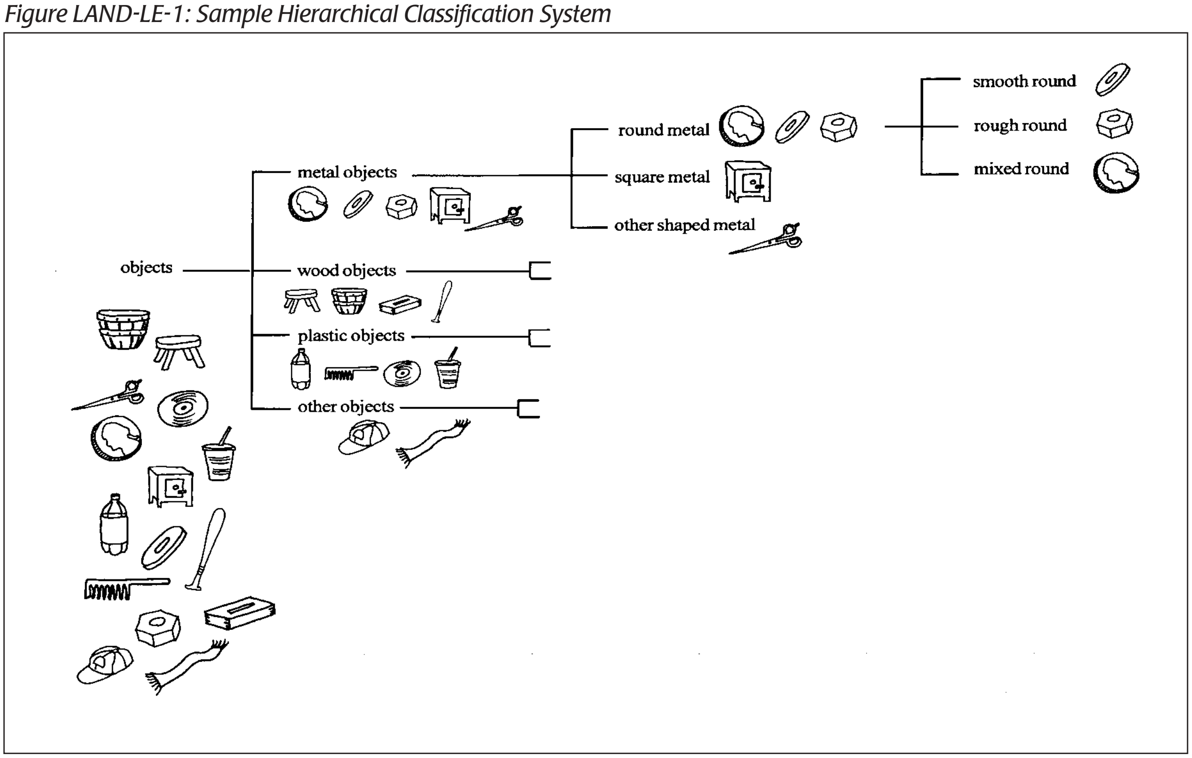
Background

Scientists classify many features of our environment such as clouds, soil, and vegetation. These classifications help us organize and understand the natural world. A *classification system* is an organized system for grouping objects into similar categories. There are two components to a classification system: *labels* and *rules*. Labels are the titles of the different classes in the classification system; rules are the tests or criteria you apply to decide which class an object belongs in. Well-defined labels and rules allow scientists to consistently describe and organize objects. For example, the Modified UNESCO Classification (MUC) System used in the GLOBE protocols allows GLOBE participants to consistently describe the land cover at any place on earth using the same labels and rules.

Classification systems are somewhat arbitrary, governed only by what we think makes sense. However, good classification systems do have three key characteristics.

1. The classes must be *mutually exclusive*. Any object must have one, and only one, appropriate class where it can be placed. For example, if a leaf could be placed in two categories, then the classes are not mutually exclusive and the system must be modified to have more detailed rules.
2. The classification system must be *totally exhaustive*. There must be an appropriate class for all potential objects. This is frequently achieved by having a catch-all class such as “other”. For example, if a leaf does not meet the criteria for any class, then the classification system is not totally exhaustive. In this case, the system must be modified, usually by adding at least one more class.
3. A classification system should be *hierarchical*. There should be multiple levels of increasing detail. At any level of detail, all the different classes should be able to “collapse” into the next less detailed level of the classification system. Figure LAND-LE-1 is an example of a hierarchical classification system of objects. Level One classes are metal objects, wood objects, plastic objects, and objects of other materials. Level Two classes within metal objects are round objects, square objects, and other shaped

Figure LAND-LE-1: Sample Hierarchical Classification System



objects. Level Three classes within square metal objects are smooth surfaces, rough surfaces, and mixed surfaces; and so on.

What To Do and How To Do It

1. Collect a variety of different leaves. If time allows, take students outside to collect leaves or ask each student to bring in 3-5 different kinds of leaves and needles. Try to get brown (old) and green (fresh) leaves. If possible, make sure there are several different varieties including plant or shrub leaves. If you live in a grassland area, you could use grasses or other herbaceous ground cover.
2. Gather the class in a circle. In the center, on the floor or on a table, spread out all of the leaves.
3. As a class, sort (classify) all of the leaves into groups of similar types. (You could also divide the class into groups and have each group perform this step. Then compare the classification systems and discuss the results.)

   Suggestion: Have the students brainstorm different characteristics that could be used for sorting the leaves. Use a chalkboard to list the suggestions. Discuss which characteristics are most important - or just have the students vote to decide the order of importance. They should realize that there is not necessarily one correct way. In this way, you will have several characteristics, in hierarchical order of importance and generality, to be used for sorting the leaves.
4. Have students sort the leaves using the chosen labels and decision rules. As the students sort the leaves, they may find that the classification system has to be modified or refined. This happens frequently in scientific projects. If there is time, students can create several different classification systems for sorting the leaves.

Discussion Questions

1. What is a classification system?
2. What labels did you use to identify different classes of leaves?
3. What rules (criteria) did you use to assign each leaf to its class?
4. How did you decide which decision criteria or rules were the most important (first) ones to use in your classification system?
5. Do all of your leaves fit into one of the classes you devised? Were there leaves that could go into more than one class? Were there some that did not fit any class?
6. How was your classification system different from other groups' or classes? How was it similar? Both systems are correct if they have what three characteristics?
7. How might you change your leaf classification system if you were sorting them for an art class? A math class?

Variations

You can use various assortments of natural or unnatural objects for this exercise (e.g. rocks, insects, buttons, shoes, and bolts). Many things work well. It is useful to use leaves, especially with younger students, to help them become familiar with local vegetation. Have your students try to sort another group of objects as an assessment activity.

Student Assessment

After completing this activity, students should be able to:

1. Describe the design of their classification system, including the basis for the labels they used to establish different classes of leaves.
2. List rules or decision criteria they used for assigning each leaf to its class.
3. Describe how they organized the hierarchical system.
4. Classify all of the leaves they collected using their system.

The ultimate measure of students' understanding of how classification systems are constructed and used will be the ease with which students are able to use the Modified UNESCO Classification (MUC) System.

Odyssey of the Eyes

Beginning Level

Purpose

To familiarize students with the importance of perspective and introduce students to various scales of remotely sensed data.

Overview

Students create a 3-D model of an area and develop a classification system for the landforms in their model. They use their eyes as remote sensors and view the model from a variety of heights and perspectives. Students then create maps of the objects they see. The maps can be used to answer certain questions about the environment.

Student Outcomes

Science Content

Physical Science

Symbols are alternative ways of representing data.

Science as Inquiry

Draw pictures that correctly portray at least some of the features of the thing being described.

Geography

<u>Primary</u>

How to describe the student's own region from different perspectives

How to display spatial information on maps and other geographic representations

The spatial concepts of location, distance, direction, and scale

<u>Middle</u>

Physical characteristics of places

How to make and use maps and to analyze spatial distributions and patterns

Enrichment

A map is a symbolic representation of a certain area.

Maps of the same area can be represented with different scales.

Field of view is how large an area you can perceive.

The field of view increases as the distance from the ground or object increases.

Remote sensing is collecting data about something from a distance.

Scientific Inquiry Abilities

Observe a landscape and design a model of it.

Draw a landscape from various perspectives.

Use different scales to view a group of objects.

Level

Primary

Time

Three to four class periods

Materials and Tools

Paper towel or toilet paper tubes

A variety of materials (boxes, cardboard, paper, paint, glue, tape, etc.) to make the models

Ruler

Writing materials

Odyssey of the Eyes Registration Form

Odyssey of the Eyes Observations of the Model

Odyssey of the Eyes Symbolic Map Data Sheet

Preparation

Gather all materials prior to the building of the model.

Using a common road map, review the basic components of maps and models such as map keys and symbols.

Prerequisites

None

Note: This activity presents concepts similar to those in *Relative and Absolute Directions Learning Activity* in the *GPS Investigation.*

Background

In the *Manual Interpretation* and *Unsupervised Clustering Mapping Protocols*, students create a land cover type map of the 15 km x 15 km GLOBE Study Site. The image you receive has been acquired from a satellite. Your students will classify the land cover types manually or with the use of a computer. They will also collect data, using the *Land Cover Sample Site Protocol*, to verify the accuracy of their resulting map. It is important to understand the concepts of modeling and remote sensing to have a clear understanding of where this information comes from and the significance of it.

Maps are very common models for representing the Earth's surface. When we create a map, we often use remote sensing to obtain the information needed to make the map. Satellite images are one type of *remotely sensed* information or data.

We may think of remote sensing as work that is only done by satellites, yet there are many instruments, including ourselves, that are used to remotely sense objects. Although students may not know it, they have a great deal of experience with remote sensing. Anytime they observe and learn about something (using their senses) without touching it; they are remotely sensing the object. Also, using a camera and a microscope are other forms of remote sensing. Cameras and microscopes give us information that we would not be able to access if we attempted to observe an object with our own limited senses.

Scientists who study land cover use a variety of aerial photography and satellite images depending on the purpose of their study. GLOBE scientists are interested in analyzing the satellite images to determine land cover types and land use changes over time.

Satellite images are made up of tiny squares called pixels. Look very closely at the satellite image of your GLOBE Study Site and you will be able to see this. Each square/pixel contains information about the dominant characteristics of a certain land cover area. Some images have pixels that represent a large area on the ground and others have pixels that represent smaller areas. The size of the area covered in a pixel is known as the resolution of the satellite image. The smaller the pixels' size, the better the resolution.

Resources (Optional)

Looking Down. Jenkins, Steve. NY: Hutton Houghton Mifflin, 1995. ISBN 0-395-72665-4

View from the Air. Lindberg, R. NY: Viking, 1995. ISBN 0-670-84660-0

Mouse Views. McMillan, B. NY: Holiday House, 1995. ISBN 0-8234-1132-x

What To Do and How To Do It

Part 1: Building and Viewing the Model

1. Students form groups and write a plan for building a model of an area, real or imagined. The schoolyard is a popular choice; however, the design of the model should be student generated. Students should list materials necessary and draw a proposed picture of their model on the *Odyssey of the Eyes Registration Form*.
2. Students will need two to three class periods to build their models.
3. Students will now use their eyes to view the model through a paper towel tube from four different views. This will give students an opportunity to view a change in *resolution* and a change in *field of view*. Have students record their observations on the *Odyssey of the Eyes Observations of the Model Work Sheet.*
   a. **Mouse View —** Observe the model from the side. Draw a map of the model and label it.
   b. **Bee's View —** Observe from 10 cm above the model. Draw a map of the model and label it.
   c. **Bird's Eye View —** With the model on the floor, observe from desk level. Draw a map of the model and label it.
   d. **Satellite View —** Observe from a second story window or stairwell. Draw a map of the model and label it.

Discussion Questions

1. Are there any visual differences between the Bee's View and the Mouse's View? What are they?

   Note: Young elementary school children often have more difficulty with the concept of "top view." Some extra time may be needed here. See resource list for suggested resources.
2. Compare your four drawings. Which view would be the most useful if you were:
   a. An eagle looking for a mouse?
   b. Deciding where to build a mall?
   c. Looking for animal tracks?
   d. Studying the extent of deforestation or reforestation?
   e. Finding a lost child in the woods?
   f. Seeing how much of the forest in your area has been damaged by pollution?
   g. Looking for a lost pin?
3. What are the advantages of using satellites to view the Earth? Are there any disadvantages?

Part 2: Making a Symbolic Map of the Model

1. Have students pick a symbol to represent each land cover type in their model (roads, rocks, playground equipment, pond, river, grass, houses, etc.). List the land cover items and symbols in the *Odyssey of the Eyes Symbolic Map Data Sheet.*
2. Use the symbols to create a map of the area on another sheet of paper.
3. Have student groups exchange symbolic maps, decipher the maps, and write a fictional story about an event that could occur within the depicted environment.

Note: If you plan on doing *Odyssey of the Eyes Intermediate Level,* please save the maps and models for comparison.

Discussion

1. If you were asked to make a map of your neighborhood, would you prefer to draw a true to life map or a map using symbols? Why?
2. Which distance (mouse, bee, bird, or satellite) would give you the best field of view for observing the area in your GLOBE Study Site? Why?

Extension

Collect a few different types of maps or ask students to research different types of maps. Discuss the purpose of each map. Explore the maps' different scales and fields of view in the discussion.

Odyssey of the Eyes

Registration Form

Name: ______________________________ **Date:** ______________________________

Write a short description of the model you are going to create in the space below.

____

____

____

____

____

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____

____

____

____

Materials Needed:	Provided By:

On the back of this page, draw a diagram of the model you are going to create.

Odyssey of the Eyes

Observations of the Model-1

Name: ______________________________ **Date:** ______________________________

Mouse View

Bee's View

Odyssey of the Eyes

Observations of the Model-2

Name: ______________________________ **Date:** ______________________________

Bird's Eye View

Satellite View

Odyssey of the Eyes

Symbolic Map Data Sheet

Name: ______________________________ **Date:** ______________________________

Land Cover Key

	Land Cover Type	Symbol
	Example: *Road*	═══════
	Example: *Tree*	▲
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		

Use the back of this paper to draw your symbolic map. Include the dimensions of the map in centimeters (length and width).

Odyssey of the Eyes
Intermediate Level

Purpose

To familiarize students with the concept of modeling as it is related to remote sensing and to the process of digitizing images.

Overview

Students will use the symbolic map created in the beginning activity to produce a digitized image. As they perform the activity, they will begin to see why ground verification of satellite data is necessary in order for scientists to create accurate models of the Earth's systems.

Student Outcomes

Science Content

Science and Technology

Scientists rely on technology to enhance the gathering and manipulation of data.

Science as Inquiry

Communications involves coding and decoding.

Tables, graphs and symbols are alternative ways of representing data.

Use numerical data in describing and comparing objects and events.

Geography

<u>Primary</u>

Maps and satellite-produced images

<u>Middle</u>

Characteristics, functions, and applications of maps, globes, satellite images

Enrichment

Objects in a remotely sensed image are interpreted and digitized into a code based upon the object's reflectance of bands of light.

The image codes are relayed through a satellite dish to a computer for storage or enhancement.

Image display is accomplished by conversion of stored data to a user-defined color-coded image.

Scientific Inquiry Abilities

Observe, digitize and interpret an image.

Level

Middle

Time

Two to three class periods

Materials and Tools

Graph paper

Pencils

Maps and models from *Odyssey of the Eyes Beginning Level*

Plastic overlay with *Odyssey of the Eyes Grid*

Odyssey of the Eyes Teddy Bear

Colored pencils

Odyssey of the Eyes Digitized Data Sheet

Preparation

Assemble the materials.

Demonstrate the process of digitizing to the class before you have students work with partners.

Prerequisites

Students should know how satellites receive information and relay it to a computer.

Odyssey of the Eyes Beginning Level is necessary for the completion of this activity.

Note: This activity presents concepts similar to those in steps 8, 9, and 10 of the *Relative and Absolute Directions Learning Activity* in the *GPS Investigation.*

Background

The sun emits energy in the form of light. This light energy reaches the earth. The light is composed of many bands of light, including visible light. Visible light is made up of red, orange, yellow, green, blue, indigo, and violet. Each object on earth reflects visible light differently. Some objects reflect all visible light (objects that appear white to us), others absorb all visible light (objects that appear black to us), and some reflect different amounts for each band of visible light. Satellites record the amount of light reflected from objects on the ground. They store this information as data or code. These codes or data are visualized on a computer and called satellite images.

What To Do and How To Do It

Part 1: How Digitized Images Are Made

Students will learn how satellites and computers communicate with each other. One student will serve as the satellite and the other will represent the computer. Using a black and white picture, the student "satellite" will scan a picture, translating it into a digitized code. The student "computer" will translate the numeric code, reproducing the image.

1. Students work in pairs. One serves as the satellite and the other represents the computer. The satellite places the plastic overlay with the *Odyssey of the Eyes Grid* over the black and white picture of the *Odyssey of the Eyes Satellite.* The satellite scans the picture, one box at a time, starting at the left-hand corner of the picture. The satellite calls out a number code for each box on the grid to his or her computer (partner). The computer writes the number code on their grid.
2. The satellite will interpret each square according to the following guidelines:
   - The satellite indicates the beginning and end of each scan line with a "0."
   - **If a box is white**: the satellite interprets the message as a "1."
   - **If a box is gray**: the satellite interprets the message as a "2."
   - **If a box is black**: the satellite interprets the message as a "3."
   - **If a box is not all black, all gray or all white:** the satellite must make a decision as to the best possible choice, "1", "2" or "3." The "satellite" should make his decision based on whether the square is mostly black, gray, or white.
3. Using a pencil, the student representing the computer translates the digital code onto the graph paper, creating a satellite image. They begin or end a line when they read a "0," leave a box blank when they read a "1," and shade in the square lightly if they read a "2" or shade in the square black, if they read a "3."

Example:

If the boxes in the first row are white, white, black, mostly black, and gray and the second row is white, gray, black, mostly white, and gray; the "satellite" would translates this to [01133200123120]. The computer writes down this code and then colors in the grid of the first row with white, white, black, black, gray and the second row with white, gray, black, white, gray.

Note: For additional practice, use student generated color pictures and different size grids.

Part 2: Making a Digitized Image Using Data From a Map Model

1. Supply each group with a plastic grid overlay (made from the *Odyssey of the Eyes Grid*). Have the students place this grid over the symbolic map from *Odyssey of the Eyes Beginning Level*.
2. Ask students to create a color and number code (key or legend) for the land cover items on their map. Assign each landform on the symbolic map a color and a number. Record this on the *Odyssey of the Eyes Digitized Data Sheet*.
3. Ask students to create the digitized code for their map:
   - Begin and end each scan line with a "0."
   - Scan each line of the symbolic map, "coding" each square with a number determined by the *Odyssey of the Eyes Digitized Data Sheet*.

- Record the numbers on the data chart.
- Review the guidelines in *Part One* of this activity for further assistance.

4. Finally, using the digitized code, ask students to select the matching colors and reproduce the map as a digitized image on a piece of graph paper.

Discussion and Assessment

1. Look at your symbolic map.
   a. What is different about the digitized map or image?
   b. What is the same?
   c. Do you think that the image and model both represent the same amount of each land cover type or landform?
2. Look at your original model.
   a. What is different about the digitized map or image?
   b. What is the same?
   c. Do you think that the image and model both represent the same amount of each land cover types or landform?
   d. Look at the symbolic map. Look for differences and similarities between the symbolic map and original model. Can you name two of each?
3. Compare and contrast maps produced by other groups:
   a. How do you know the maps are accurate?
   b. What happens to land cover types that are a small size when you draw a symbolic map or digitize an image?
   c. What happens to land cover types that have irregular shapes?
   d. How do these changes affect what type and amount of land cover you see?
4. What function does the satellite perform when mapping?
5 What function does the computer perform when mapping?
6. Why are maps from one group of students different than maps from another group?
7. Do the colors chosen to represent each type of land cover have to reflect what you see on the ground?
8. How would digitizing your model be different if the model were illuminated under blue light?

Note: Ground verification is what you are doing in some of the *Land Cover/Biology Protocols*. In the *Land Cover Sample Site Protocol*, students verify what is actually on the ground compared to what is interpreted by a satellite image or a model.

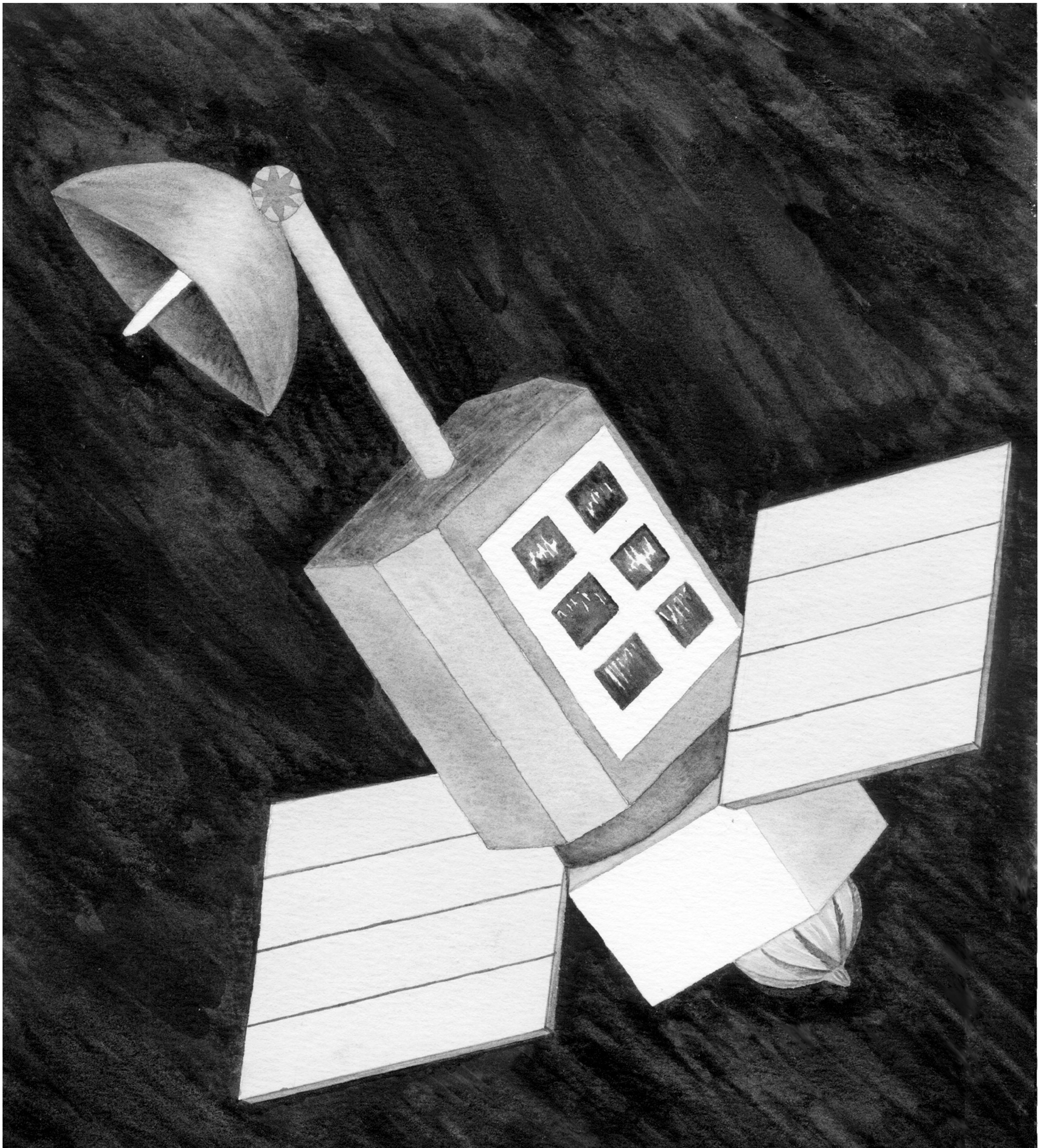
Extension

The Landsat satellite collects the data for your GLOBE Study Site. Label the parts of the Landsat satellite and describe what each part does. For diagrams and information about Landsat, see the Land Cover/ Biology GLOBE Web site at
http://www.globe.unh.edu
or the Landsat NASA Web site at
http://geo.arc.nasa.gov/sge/landsat/landsat.html

Acknowledgment
Satellite art by Sherri Wormstead

Odyssey of the Eyes Large Grid

Odyssey of the Eyes Small Grid



Odyssey of the Eyes
Digitized Data Sheet

Name: ______________________________ Date: ________________________________

Land Cover Type	Symbol	Number	Digitizing Color
Example: *Road*	════════	1	Black
Example: *Tree*	▲	2	Green

Digitized Code

Use a 0 to indicate the beginning and ending of each scan line.

For the large-sized grid squares, use the following lines as an example of how to set-up your paper.

0 ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ 0

0 ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ 0

For the small-sized grid squares, use the following lines as an example of how to set-up your paper.

0 ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ 0

0 ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ 0

Odyssey of the Eyes
Advanced Level

Purpose
To help students understand the connection between remote sensing technology, computer imagery and land cover assessment and to demonstrate how a satellite sensor relates information to a computer

Overview
Students translate their maps into digital code and exchange the digitized versions of their maps with students in another school or classroom for translation into a color map. Each group of students recreates the original image's land cover types.

Student Outcomes
Science Content
Science and Technology

Clear communication is an essential part of doing science.

Communications involves coding and decoding.

Tables, graphs and symbols are alternative ways of representing data.

Geography

Primary

Maps and satellite-produced images

Enrichment

Image display is accomplished by conversion of stored data to a user-defined color-coded image.

Scientific Inquiry Abilities
Observe, interpret and classify an image using the data given.

Analyze how the image interpretation might differ between groups.

Level
All

Time
Three to four class periods

Materials and Tools
Graph paper

Colored pencils

Digitized map/image produced from Part 2 of *Odyssey of the Eyes Intermediate Level*

Internet (optional)

Preparation
Assemble the materials.

Contact another classroom or school to exchange digitized maps with.

Prerequisites
The *Odyssey of the Eyes Beginning* and I*ntermediate Levels* are necessary to complete this activity.

Note: This activity presents concepts similar to those in steps 8, 9, and 10 of the *Relative and Absolute Directions Learning Activity* in the *GPS Investigation.*

What To Do and How To Do It

1. In the previous activity, *Odyssey of the Eyes Intermediate Level*, students translated their map models into a digitized code. Type this digitized code into a word processor. Use "0" to begin and end each line of the map. Allow the numbers to "word wrap" on the screen so that the map pattern is not visible in the message.

Example:

0111122001111330024643400246444002556550044444440011112200111133001111330
0111112200111133001111330024643400246444002556550044444440011112200111133
0024643400246444002556550024643400246444002556550044444440011112200255655
0044444440011112200111133001111330011112200111133001111330024643400246
44400255655004444444001111220

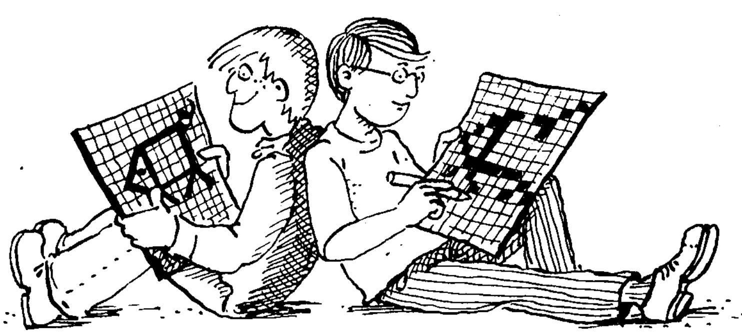
2. Include the key (from the *Odyssey of the Eyes Digitized Data Sheet)* to translate the codes to colors.

    Example:
    1 violet
    2 indigo
    3 green
    4 yellow
    5 orange
    6 red

3. Exchange keys and digitized codes with students in another class or school. This exchange can be done on the Internet, by exchanging disks between schools or classes, or just by exchanging hard copies of the information.
4. Once your students receive the code from the other school or class, translate it into a color map using the key. Your students will produce a false color image.
5. Return the completed maps to the sending school for verification.

Discussion

1. What are the dominant land cover types on your false-color image?
2. Can you recreate a sketch of a map or a model of the area from the false-color image?



Source: Jan Smolik, 1996, TEREZA, Association for Environmental Education, Czech Republic

Bird Beak Accuracy Assessment

Purpose

To quantitatively evaluate the accuracy of a classification and understand a simple difference/error matrix

Overview

Students sort birds into three possible classes based on each bird's beak: carnivores (meat eaters), herbivores (plant eaters), and omnivores (meat and plant eaters). Students compare their answers with a given set of validation data and generate a difference/error matrix. Students discuss how to improve their accuracy based on identifying specific mistakes they made as indicated by the difference/error matrix.

Student Outcomes

Science Concepts

Physical Science

Objects have observable properties that can be measured using these properties.

Objects have observable properties.

Life Science

Organisms relate to their environment.

Scientific Inquiry Abilities

Identify decision criteria for a classification system, and use it to classify birds.

Collect and interpret validations data.

Use numerical data for in describing and comparing the accuracy of the classification.

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate procedures, descriptions, and predictions.

Specific skills

Level

Middle, Secondary

Time

One class period

Materials and Tools

Master set of bird pictures

Master validation sheet

Overhead showing a sample bird classification work sheet

Set of bird pictures for each student group

Student Activity Guide for each student group

Preparation

Reproduce the student *Work Sheets* and the bird picture sets without the answers on the back.

Prerequisites

Ability to classify (see *Leaf Classification Learning Activity)*

Understanding of fractions and/or percentages

Background

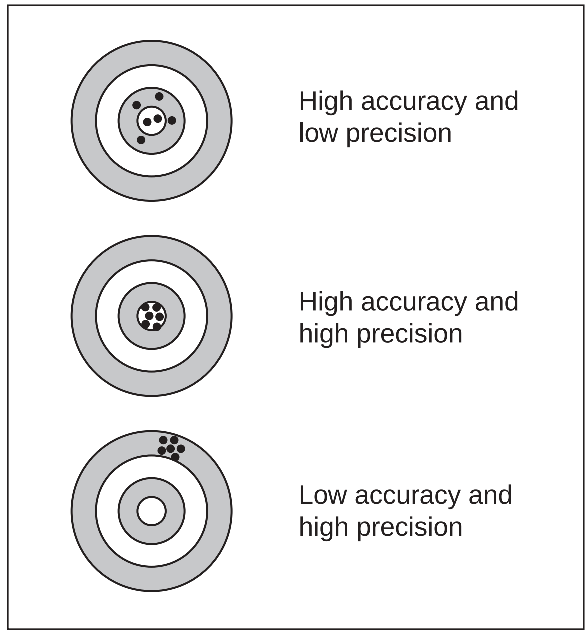
In the *Leaf Classification* learning activity, students learned to create and use a classification system. In this activity, students will learn to determine how good of a job they did classifying objects into a system.

Scientists classify many features of our environment such as animal species, plant species, land cover types, and soils. The ability to classify (or group) is a fundamental mechanism for helping to organize and understand the natural world. One application of remote sensing is to create a land cover type map of an area using satellite data for the classification. Since this map may be used to make decisions, it is important to know the accuracy of it. Comparing the results of a classification to a highly accurate data set (called *validation data*) is called *accuracy* assessment. This comparison is represented in a table called a *difference/error matrix*. Accuracy percentages of the classification are computed from the matrix.

This learning activity will introduce these concepts with a very simple classification of birds using just the shape of their beaks. Each student or group will classify each of 10 birds as an herbivore, carnivore, or omnivore. Each student or group will generate a difference/error matrix by comparing their classification with the validation data (provided). GLOBE students will use this exact same process to assess the accuracy of the maps they derive from the satellite imagery of their GLOBE Study Site. Land Cover Sample Sites visited on the ground will be used as validation data to compare with the student map classification generated from classifying the satellite data.

Key Terms and Concepts

Accuracy: Accuracy is the degree of conformity to a standard or accepted value. This is not the same as precision. Precision is the closeness of several measures to each other or the repeatability of a measurement.



Difference/Error Matrix: A Difference/Error Matrix is a table of numbers organized in rows and columns that compares a classification to validation data. The columns represent the validation data while the rows represent the classification generated by students. A difference/error matrix is a very effective way to represent accuracy. Correct and incorrect classifications can be compared for each category and used to improve the accuracy of the original classification. See the *Accuracy Assessment Tutorial* in the *Appendix*

Validation Data: Validation data are data collected with a presumed high degree of accuracy. A classification of items (birds in this exercise) is compared to validation data: 1) to improve the decision criteria for the classification 2) to better understand the sources of error in the classification; and 3) to assess the accuracy of the classification data.

Pre-Activity Discussion Questions

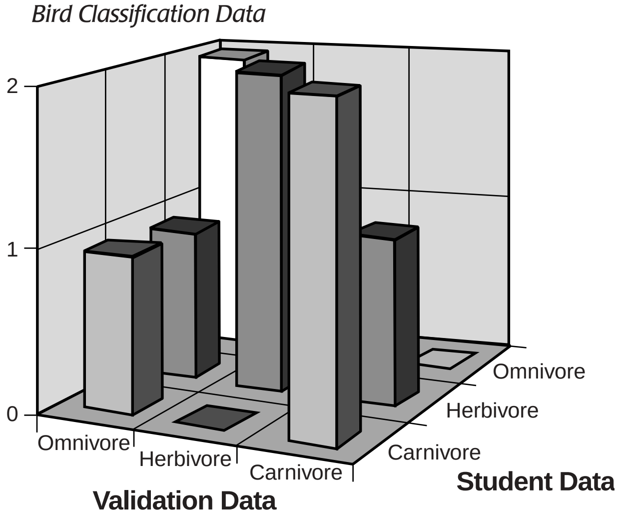
To prepare your students, discuss the following questions before starting the activity:

- Why do we organize or sort objects into groups?
- How do we sort these objects?
- Name three examples of objects that are commonly sorted into groups.

Activity Adaptations

1. A visual interpretation can be used instead of mathematically calculating the overall accuracy.
   - Layout a 3-cell x 3-cell grid on a sheet of paper numbered like the cells in the difference/error matrix. Visually represent the number of birds in each box by either graphing or physically stacking blocks in the boxes. The tallest columns should be along the diagonal of the grid.
   - If the class has access to computer spreadsheets, a 3-D graph can be created to represent the answers. Figure LAND-BI-1 shows the data from the example difference/error matrix graphed in a 3-D format.
2. The entire class can also create one difference/error matrix together on the board.

Figure LAND-BI-1: 3D Difference/Error Matrix of Sample Bird Classification Data



Assessment

1. Discuss the results of the activity with the following questions:
   a. How did different students' results vary?
   b. Why do students think this happened?
   c. What other classifications might be compared using a difference/error matrix (e.g., maps identifying land cover for a specific location versus carefully checking the same location in person).
2. Add two more data pairs (classification and validation data) and ask students to put these in the error matrix and recalculate any changes in accuracy.
3. Ask students to explain:
   a. how the difference/error matrix is constructed
   b. how data is entered
   c. how to calculate the overall accuracy
4. Examine your difference/error matrix to identify the most common errors.
5. For advanced students, explain the difference between user and producer accuracy.

References

Peterson's Field Guide to Birds

Audubon Field Guides

The Illustrated Encyclopedia of Birds: The Definitive Reference to Birds of the World. Consultant-in Chief Dr. C. Perrins. New York: Prentice Hall Press, 1990.

Check local resources for regional guides

Acknowledgment
Art by Linda Isaacson

1

2

3

4

1. Western Greenfinch
(*Carduelis chloris*)

This bird (14.5 cm in size) lives in open woodland, bushes, and gardens in Europe, Northern Africa, Asia Minor, Middle East, and Central Asia. Its diet consists of nuts and seeds, especially sunflower seeds and peanuts.

Classification:

HERBIVORE

2. European Starling
(*Sturnus vulgaris*)

This bird (21 cm in size) lives in open woods, parks, and gardens in Europe and Western Asia, and has been introduced to North America, South America, Southern Australia and New Zealand. It eats both plants and animals.

Classification:

OMNIVORE

3. Bicolored Wren
(*Campylorhynchus griseus*)

This bird (22 cm in size) lives in dry savanna, cactus scrub, and open woods in Colombia, Venezuela, Northern Brazil and Guyana. Its finds insects and insect eggs by peering and poking into crevices on the ground.

Classification:

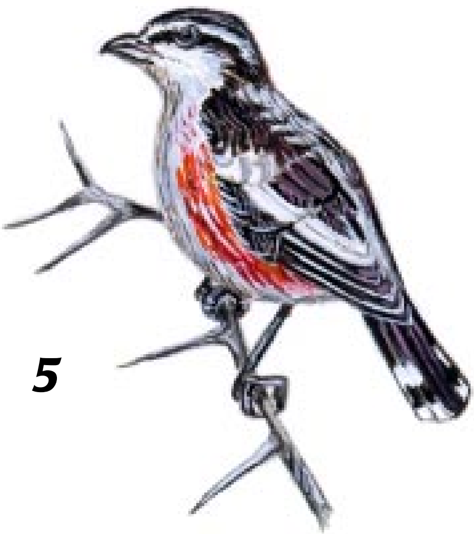
CARNIVORE

4. Rose-ringed Parakeet
(*Psittacula krameri*)

This bird (41 cm in size) lives in woodlands and farmlands in Central Africa east to Uganda, India, Sri Lanka, and has been introduced to Middle and Far East, North America, England, Netherlands, Belgium, and West Germany. It eats grain or ripening fruit.

Classification:

HERBIVORE



5

6

7

8

6. Clay Colored Robin
(*Turdus grayi*)

This bird (23-24 cm in size) lives in open woodland, woodland edge and clearings, usually near streams in Southeast Mexico, Central America, coastal Colombia. It eats insects, earthworms, slugs and lizards as well as fruit.

Classification:

OMNIVORE

5. Bru Bru Shrike
(*Nilaus afer*)

This bird (15 cm in size) lives in savanna woodland and sometimes the forest edge in tropical Africa. It eats insects and catches food on the wing.

Classification:

CARNIVORE

8. Eurasian Jay
(*Garrulus glandarius*)

This bird lives in oak woods, and open country in Western Europe, across Asia to Japan and Southeast Asia. It eats insects, beech nuts and acorns.

Classification:

OMNIVORE

7. Pine Grosbeak
(*Pinicola enucleator*)

This bird (20 cm in size) lives in the coniferous and scrub forests of North and West North America, North Scandinavia and Siberia. It eats berries and buds on the ground or in treetops.

Classification:

HERBIVORE

9

10

10. Hermit Thrush

(*Catharus guttatus*)

This bird (15-20 cm in size) lives in woodlands, forest edges and thickets in North and Central America. It eats insects, spiders, snails, earthworms and salamanders as well as fruits and seeds.

Classification:

OMNIVORE

9. Common Tree Creeper

(*Certhia familiaris*)

This bird (12.5 cm in size) lives in woodlands particularly coniferous woodlands in Western Europe and Japan. It eats insects and insect eggs gleaned from tree bark.

Classification:

CARNIVORE

Reference: *The Illustrated Encyclopedia of Birds: The Definitive Reference to Birds of the World.* Consultant-in Chief Dr. C. Perrins. New York: Prentice Hall Press, 1990.

Table LAND-BI-1: Bird Classification Validation Data Sheet

Bird ID	Bird Name	Classification
1	Western Greenfinch	Herbivore
2	European Starling	Omnivore
3	Bicolored Wren	Carnivore
4	Rose-ringed Parakeet	Herbivore
5	Bru Bru Shrike	Carnivore
6	Clay Colored Robin	Omnivore
7	Pine Grosbeak	Herbivore
8	Eurasian Jay	Omnivore
9	Common Tree Creeper	Carnivore
10	Hermit Thrush	Omnivore

Bird Beak Accuracy Assessment
Student Activity Guide

Name: ______________________________ **Date:** ________________

Overview

Scientists classify many features in our environment, such as species, land cover types and rock types. These classifications, or categories, help us to organize and understand the natural world. In order for these classifications to be useful to scientists, we need to know how accurate they are. A difference/error matrix is the basic tool used to measure the accuracy of a classification procedure. This difference/error matrix also shows us where there was confusion or difficulty classifying certain classes.

Materials

A set of 10 bird pictures, *Sample Beak Types*, *Bird Accuracy Assessment Work Sheet, Bird Difference/Error Matrix Work Sheet*

What To Do and How To Do It

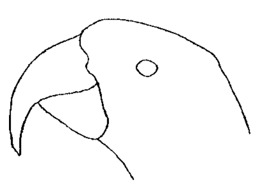
In the following activity you will be classifying types of birds as:

Symbol	Bird Classification	Description	Food Preference
C	carnivores	meat eaters	fish, meat, insects, worms, small mammals
H	herbivores	plant eaters	vegetation, seeds, nuts, and berries
O	omnivores	plant and meat eaters	all of the above

The size and shape of the bird's beak will usually indicate its preferred food type. Many birds are opportunistic however, and will supplement their preferred diet with a variety of foods when a scarcity of food requires it.

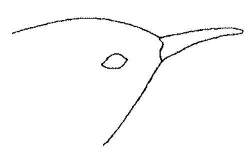
Herbivore Beak Types

Finch Type: Heavy wedge shaped beaks are good for cracking nuts and seed



Parrot Type: Thick curved upper and lower beak are also for cracking nuts or tearing fruit apart. The upper beak as a sharp point and usually curves over the lower beak.

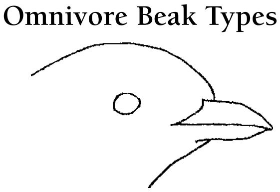
Carnivore Beak Types



Insect Eater Type: Long slender, slightly curved beaks are used to probe for insects and spiders in tree bark and soils

Meat Eater Type: Shorter than the insect eater, upper beak has a sharp curved overhanging tip and straight lower beak specialized for tearing meat.

Omnivore Beak Types



Jay Type: Wide, medium length beak is used for eating insects, fruit, seeds, and even carrion.

Thrush Type: Shorter and more slender than the Jay type, also for eating meat, plants, and insects.

Bird Beak Accuracy Assessment

Student Activity Guide-2

Name: ____ **Date:** ______________________

Procedure

1. Look at each of the birds on the cards (numbered 1-10) and classify it as a carnivore, herbivore, or omnivore. Record each answer in the "Student Classification" column.
2. Your teacher will provide the information to be recorded in the column labeled "Validation Data." Be sure to fill in this column accurately, these data will be needed to complete the Bird Difference/Error Matrix.
3. Look at all ten pairs and mark each matching pair with a "✔" and each different (incorrect) pair with an "✘" in the last columns.

Bird Accuracy Assessment Data

Bird ID Number	Student Classification	Validation Data	✔	✗
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

4. Fill in the Difference/Error Matrix using the *Bird Accuracy Assessment Student Field Guide.*

Bird Difference/Error Matrix

Validation Data

Student Classification	Carnivore	Herbivore	Omnivore	Row Totals
Carnivore				
Herbivore				
Omnivore				
Column Totals				

Be sure to check with your teacher when you have entered all your data pairs and summed the columns and rows.

Bird Beak Accuracy Assessment
Student Activity Guide-3

Name: ____ **Date:** ______________________

Note: The numbers in the outlined boxes (the major diagonal), with the exception of the lower right hand box, are classified correctly. Go through the other boxes in the matrix to find any incorrect classifications. The Bird Difference/Error Matrix indicates the most difficult classes to identify. The numbers off the major diagonal represent “incorrect” classifications.

Which difference/error box has the largest number?

5. Calculate the overall accuracy as outlined in the *Bird Beak Accuracy Assessment Student Field Guide.*

Discussion

1. Did you have difficulty correctly classifying a particular category? Why?
2. How could you reduce the number of errors next time?
3. What are some other ways you can classify birds?
4. Do you have any suggestions for improving the classification criteria?
5. How did other students’ results vary? Compare your difference/error matrix to other students’ difference/error matrices to see who had the largest number of accurate answers and to see if other students or groups made mistakes classifying the same categories. What caused the mistakes?
6. What other measures can be used to evaluate data quality?

Further Investigations

1. Combine all the class data to create a class difference/error matrix. Calculate the overall accuracy of the class. Which do you think is more accurate, your matrix or the combined class results? Why?
2. Try to develop your own criteria for classifying a group of objects (for example, insects).

Bird Beak Accuracy Assessment

Student Field Guide

Task:

Assess the accuracy of your bird classification. You will create and analyze the data using a difference/error matrix.

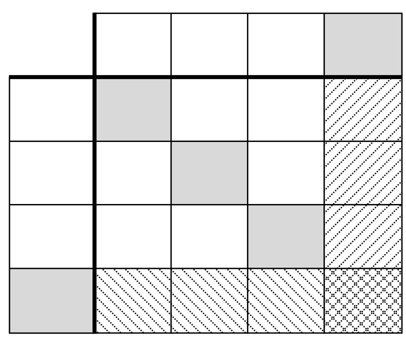
What You Need:

- ☐ Completed *Accuracy Assessment Data Work Sheet*

Bird ID Number	Student Classification	Validation Data	✔	✗
1	O	H		✗
2	O	O	✔	
3	C	C	✔	
4	H	H	✔	
5	C	C	✔	
6	C	O		✗
7	H	H	✔	
8	O	O	✔	
9	H	C		✗
10	H	O		✗

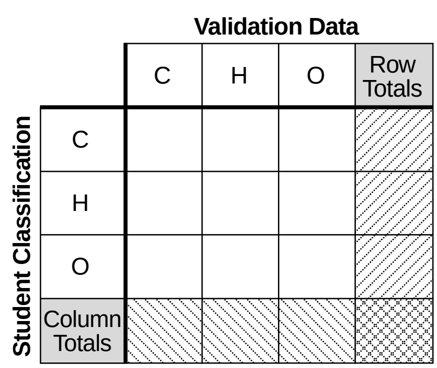
- ☐ Graph paper or blank paper
- ☐ Pencil or Pen
- ☐ Calculator
- ☐ Ruler/Straight Edge

1. **Build an empty difference/error matrix.**
   a. There should be a column and row in the matrix for every type of bird class that occurs on your *Accuracy Assessment Data Work Sheet.*
   b. Add two extra rows and two extra columns for the titles and totals.



Note: The example difference/error matrix is shaded to help show the titles, totals, and data in agreement. There is no need to shade your matrix.

2. **Label Your Difference/Error Matrix with Titles and Bird Classes.**
   a. Label the top, "*Validation Data.*"
   b. Label the left side, "*Student Classification.*"
   c. Label the columns and rows of the difference/error matrix with the bird classes from the *Accuracy Assessment Data Work Sheet* (C, H, O). Put the classes in the same order from the upper left-hand corner going down (row titles) and across (column titles).
   d. Label the last row "*Column Totals.*"
   e. Label the last column, "*Row Totals.*"



3. Tally each row of data from the completed *Accuracy Assessment Data Work Sheet.*

a. Find the row in your matrix matching the Student Classification.

E.g., In the first row of the completed *Accuracy Assessment Data Work Sheet*, the Student Classification is "O" (Omnivore).

Validation Data

Student Classification	C	H	O	Row Totals
C				
H				
O				
Column Totals				

b. Find the column in your matrix matching the Validation Data.

E.g., In the first row of the completed *Accuracy Assessment Data Work Sheet,* the Validation Data is "H" (Herbivore).

Validation Data

Student Classification	C	H	O	Row Totals
C				
H				
O				
Column Totals				

c. Put a tally mark (I) in the box where the row and column overlap

Validation Data

Student Classification	C	H	O	Row Totals
C				
H				
O		I		
Column Totals				

d. Finish tallying for all the rows of data in your *Accuracy Assessment Data Work Sheet.*

Validation Data

Student Classification	C	H	O	Row Totals
C	II		I	
H	I	II	I	
O		I	II	
Column Totals				

4. Calculate Totals

a. **Calculate Row Totals –** For each row, add up all tally marks in the row and put that value in the *Row Total* box for that row.

Validation Data

Student Classification		C	H	O	Row Totals
	C	II		I	3
	H	I	II	I	
	O		I	II	
	Column Totals				

b. **Calculate Column Totals –** For each column, add up all tally marks in the column and put that value in the *Column Total* box for that column.

Validation Data

Student Classification		C	H	O	Row Totals
	C	II		I	3
	H	I	II	I	4
	O		I	II	3
	Column Totals	3			

c. **Total Data Samples**

Add up the *Row Totals* boxes. 3 + 4 + 3 = 10

Add up the *Column Totals* boxes. 3 + 3 + 4 = 10

The sum of the column totals should equal the sum of the row totals. This should be equal to the total number of data samples (rows) on your *Accuracy Assessment Data Work Sheet.*

Put this number in the bottom right box (where *Row Totals* and *Column Totals* overlap).

If the sum of the row totals does not equal the sum of the column totals, recheck your math and tallies.

Validation Data

Student Classification		C	H	O	Row Totals
	C	II		I	3
	H	I	II	I	4
	O		I	II	3
	Column Totals	3	3	4	10

5. Calculate the Overall Accuracy

$$\text{Overall Accuracy} = \frac{\text{sum of major diagonal tallies}}{\text{total number of samples}} \times 100$$

Validation Data

Student Classification		C	H	O	Row Totals
	C	II		I	3
	H	I	II	I	4
	O		I	II	3
	Column Totals	3	3	4	10

Add the tallies in all the boxes on the major diagonal of your matrix except the lower right-hand Total box. Divide this sum by the total number of samples (the value in the lower right-hand Total box). Multiply by 100 to convert it to a percentage.

$$\text{Overall Accuracy} = \frac{(2 + 2 + 2)}{10} \times 100 = 60\%$$

Discovery Area Post-Protocol

Purpose

To use a land cover type map to make environmentally sound decisions

Overview

Students analyze their land cover type maps to determine where to place a hospital while considering potential environmental impacts. Students present their work in a mock town meeting. At the conclusion of the meeting, students should reach a final decision.

Student Outcomes

Science Concepts

Life Science

Earth has many different environments that support different combinations of organisms.

Humans can change natural environments.

Geography

How humans modify the environment

Scientific Inquiry Abilities

Use the land cover type map to discuss how a structure will affect organisms using a particular land cover type.

Analyze different scenarios that change the land cover types of an area.

Evaluate different solutions to various scenarios.

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate procedures, descriptions, and predictions.

Level

All

Time

Two to four class periods

Materials and Tools

Classified land cover type map from *Manual Interpretation* or *Unsupervised Clustering Mapping Protocols*.

Prerequisites

Manual Interpretation or *Unsupervised Clustering Mapping Protocol.*

Familiarity with the terms: dominant, subdominant, rare, and isolated

Group presentation skills

What To Do and How To Do It

1. Divide the class into groups of three or four.
2. Discuss what land cover types are classified on their land cover type map. Have them list them in the table on the *Hospital Planning Sheet*.
3. As a class, thoroughly discuss each of the land cover types. You may want to use the ideas and questions below to guide the discussion. Pay close attention to living as well as non-living constituents.
   - Is there vegetation in this land cover type? What kinds?
   - What animals depend on the vegetation in the land cover type?
   - What is the amount of suitable land cover needed for those plants and animals?
   - What part does the land cover type play in watershed issues?
   - Where are different land cover types located in relation to each other?
   - Are there any parks, protected or threatened areas?
4. Each group must decide the three most desirable locations for a hospital, including the parking lots and roads.
   - Using the chart, students compare the land cover areas. How will the proposed development affect the plants and animals in those areas? How do people presently use those areas?
   - The students discuss the options with their group and narrow their decision to one.
5. Once they have narrowed their choices down, students construct a presentation board with their proposal and prepare a presentation for the class explaining their choice of site.
   - Enlarge the original classified image so that the land cover areas are easily recognizable.
   - Place the hospital, road, and parking lots that will be part of the development on the classified image, basing the size on other buildings in the image.
6. Town meeting: Each group explains their location choice for the hospital. Each presentation is intended to persuade classmates that the team has picked the best location. Students role-play local citizens. Asking questions related to environmental issues should be encouraged.

   Note: To add more reality to the exercise, assign roles to students: Nurse, Forest Ranger, Unemployed Person, Watershed Ecologist, Student, Hospital Board of Directors, Sick Person, Hotel Owner, New Doctor, etc. Have each student role-play during the site selection and/or mock town meeting.
7. After viewing all the presentations, ask each student or group to indicate which location they liked best and why. Vote on the best place for the hospital.

Discussion

1. Is there agreement with the class decision? Why or why not?
2. Could there be more than one answer?
3. How did the class/students decide on their final location? What considerations played the most important roles? Land cover type? Animal life? Plant life? Water source? Wetland? Loss of buildings? Trying to limit new roads? Existing uses of the land? Need for the hospital within the boundaries of their GLOBE Study Site? Etc.

Assessment

1. A rubric can be created for the presentation. It might include: all members participate in the presentation, group's ability to work together to make decisions, all ideas accepted for discussion, skills such as clear speaking voice, speed of speech, ability to answer questions from the audience, and level of preparation. You can also include the presentation board in the assessment. The rubric for this might include neatness, location choice clearly marked and visual presentation.
2. For individual assessment, ask the students to write out their choice of location and why they picked this area. They should attempt to take environmental factors into consideration and consider the map information as a whole.

Discovery Area Post-Protocol

Hospital Planning Sheet

Name: ____**Date:** ______________________

Land Cover Types in your satellite image:

Most Common Land Cover Types	Less Common Land Cover Types	Least Common Land Cover Types
1.	1.	1.
2.	2.	2.
3.	3.	3.
4.	4.	4.

Using the information above and your class discussion, decide as a group where to place a hospital that is 9000 m^2 in size so that it has the least impact on the environment. This size is approximately 10 pixels that can be arranged however your group decides. It should be easily accessible to roadways and to the majority of the population in your area. You should include at least two pixels for a parking lot and other grounds (garden, courtyards, etc.). Use your satellite image to determine your group's three choices. Be sure to justify each choice.

Choice	Reasons

Narrow down your three choices to one. In the space below, explain why you chose this site and what benefits it has over the other choices.

____

____

____

____

____

____

____

Using GLOBE Data to Analyze Land Cover

Purpose

To develop hypotheses about which environmental factors are most important to plants growing in a local Land Cover Sample Site by comparing local GLOBE data to those of other GLOBE schools reporting the same MUC class

Overview

Using GLOBE Visualizations, students will identify two other GLOBE schools that have reported the same MUC class and compare their temperature, precipitation and soil moisture to their own. They will try and identify which environmental factors are similar and which vary, suggesting which are more important in determining plant communities.

Student Outcomes

Science Concepts

Geography

- How to use maps (real and imaginary)
- The physical characteristics of place
- The characteristics and spatial distribution of ecosystems
- How humans modify the environment

Scientific Inquiry Abilities

- Use GLOBE Web site to gather, analyze and interpret data.
- Identify answerable questions.
- Design and conduct scientific investigations.
- Use appropriate mathematics to analyze data.
- Develop descriptions and predictions using evidence.
- Recognize and analyze alternative explanations.
- Communicate procedures, descriptions, and predictions.

Level

Middle and Secondary

Time

1-2 class periods for data collection, 2 class periods for data analysis. Additional time will be necessary if a report is to be generated.

Materials and Tools

- Internet access
- Paper
- Colored pencils
- Atlas
- *Basic Information Work Sheet*
- *Data Gathering and Organizing Work Sheet*
- *Data Analysis Work Sheet*

Preparation

Choose one of the natural cover MUC classes you have identified in a Land Cover Sample Site.

Make copies of the appropriate *Work Sheets*.

Prerequisites

Complete measurements for at least one natural cover Land Cover Sample Site. This site should have a complete MUC class of at least 3 or 4 digits.

Your school system should have data for several months for Temperature, Precipitation, and Soil Moisture.

Basic understanding of ecosystems

Introduction

An **ecosystem** is a major interacting system that involves both living organisms and their physical environment. As a science, ecology attempts to explain why particular plants and animals can be found living together in one area and not in others; why there are so many organisms of one sort and so few of another; what changes one might expect the interactions among them to produce in a particular area; and how ecosystems function, with particular reference to the flow of energy, the use of organic compounds, and the cycling of chemical elements.[1] It is important to consider the ecosystem as a whole when drawing conclusions about a particular component, such as vegetation type. This activity is an ecological approach to analyzing land cover.

What To Do and How To Do It

This learning activity is organized according to the scientific method:

Scientific Method	This Learning Activity	Level
Research Question and Hypothesis Development	Which environmental factors are most important to plants growing in a local Land Cover Sample Site?	Intermediate and Advanced
Data Collection	Use GLOBE Visualizations and an atlas to obtain GLOBE data from other schools *Basic Information Work Sheet* *Data Gathering and Organization Work Sheet*	Intermediate and Advanced
Data Analysis and Results	Answer questions which analyze the data obtained to compile results or findings *Data Analysis Work Sheet*	Intermediate and Advanced
Conclusions	Summarize your results and expain what your findings mean in a report *Conclusions – Project Report*	Advanced

This activity is designed for both intermediate and advanced levels. To take this activity to an advanced level, there is a culminating section, *Conclusions - Project Report,* in which the students produce a report summarizing the interactions of the GLOBE measurements and how they affect the type of land cover. It is envisioned as a long-term assignment or final term project. This is a good learning activity to use GIS software if it is part of your school's software library.

Implementation Suggestions

- Complete the *Basic Information Work Sheet* as a class.
- Organize the class into working groups.
- Have each group of students collect and interpret one particular set of data (e.g., Temperature) following the appropriate section of the *Data Gathering and Organizing Work Sheet.*
- Have each group report their results (perhaps photocopy a set for each group) to the whole class to complete the data analysis and conclusions.

[1] Peter H. Raven, Ray F. Evert, and Susan E. Eichhorn. 1992. *Biology of Plants, 5th ed.* New York, NY: Worth Publishers.

Helpful Hints

- Prepare students for this activity by doing a brief ecology unit, discussing the characteristics of your *natural cover* Land Cover Sample Sites.
- During data analysis, periodically pause to review the objectives of this activity and to share insights.
- For a more inquiry-based activity, considering what other measurements your school /school system has conducted, have students develop their own research questions about land cover. They can be questions specific to one other measurement (e.g., precipitation or soil characteristics). They can still follow the appropriate sections of the learning activity for data collection and analysis.

Basic Data Collection

Note: The GLOBE Web site pages change in appearance from time to time and may not look exactly as they are pictured.

1. Review the MUC code and corresponding land cover type obtained for one of your natural cover Land Cover Sample Sites [MUC level 1, Closed Forest (0), Woodland (1), Shrubland (2), Dwarf-Shrubland (3), Herbaceous Vegetation (4), Barren Land (5), Wetland (6)]. Make sure your MUC is taken to the highest level possible (3 or 4 digits).

2. Obtain the name and location of two GLOBE schools who have reported the same MUC code:
   a. Enter the GLOBE server as you normally do. There is no need to log in.
   b. Go to GLOBE Visualizations.
   c. Create a graph or map using the land cover MUC data. Use “Other Options” to map the specific MUC class to Level 2, 3, or 4.
   d. Select the show table option to list schools with the same MUC class.

   Note: What To Do If There Are No Matching MUC Classes
   Find MUC codes with the highest level of agreement. For example, if your MUC code is 4133 (tall graminoid herbaceous vegetation with broad-leaved deciduous shrubs), you can use a MUC Code that matches to level 3, such as 413 (tall graminoid herbaceous vegetation with shrubs).

   e. Filling out the *Basic Information Work Sheet*, write down the MUC code, name of the school, city name, country, latitude, longitude, and elevation for the two schools.

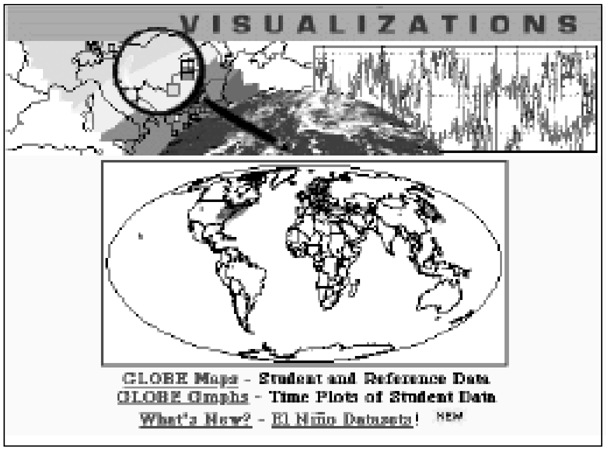
Research Question and Hypothesis Development

Discuss the research question: Which environmental factors are most important to plants growing in a local Land Cover Sample Site? Encourage the development of hypotheses that address this question.

Obtain Other GLOBE Data for These Schools with the Same MUC Class.

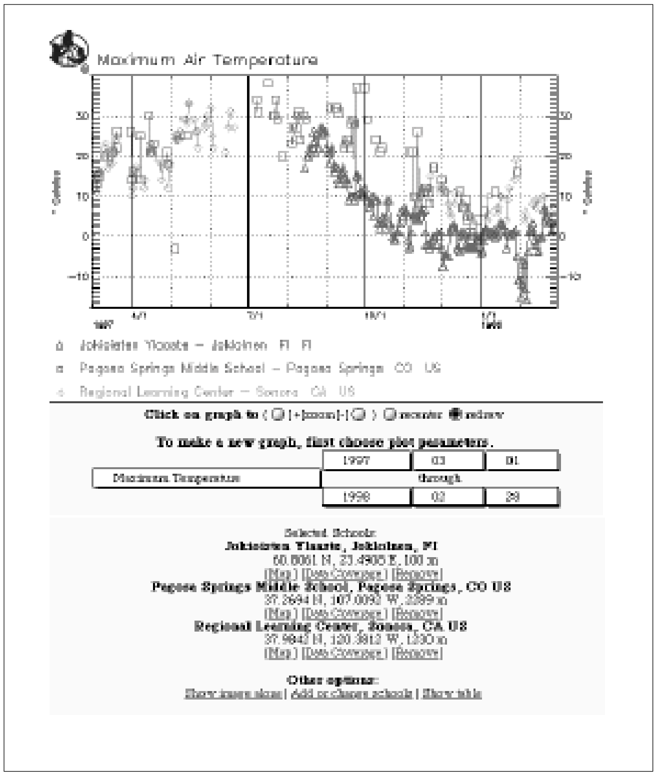
Note: If the schools chosen do not have all of the recommended data, try choosing a different school to analyze or work with the data you are able to obtain. Data gaps are a reality of ecosystem science.

1. Enter the GLOBE server as you normally do.
2. Go to GLOBE Visualizations:



3 Add each of the schools you are studying to a single graph.

4. Select one of the GLOBE parameters and adjust the dates to create *Time Series Plots* for one full year. You can adjust the dates to analyze a few years, one year, one month, etc. Your graph should look similar to the one below.



5. Following the *Data Gathering and Organizing Work Sheet* questions, create *Time Series Plots* for current temperature, maximum temperature, minimum temperature, rainfall, snowfall, and soil moisture (30 cm).

Using GLOBE Data to Analyze Land Cover

Basic Information Work Sheet

Our School

MUC Code ____________________ Land Cover Type ____

Latitude ______________________ Longitude ____________________ Elevation ______________________

Comparison School #1

MUC Code ____________________ School Name ____

City ____ Country________________________

Latitude ______________________ Longitude ____________________ Elevation ______________________

Comparison School # 2

MUC Code ____________________ School Name ____

City ____ Country________________________

Latitude ______________________ Longitude ____________________ Elevation ______________________

Using GLOBE Data to Analyze Land Cover

Data Gathering and Organizing Work Sheet-1

These questions are organized to help you record the data from GLOBE Visualizations. You might want to download and plot data instead of sketching the graphs from the GLOBE Web site. You can also click on the graph and save it as a graphics file to disk.

Temperature

1. Sketch the graph from the *Time Series Plot* for the current temperature of your school and the others using a different color for each school.
2. Estimate the highest temperature for each school you chose using the maximum temperature Time Series Plot.
3. Estimate the lowest temperature for each school you chose using the minimum temperature Time Series Plot.

Precipitation (Rainfall and Snowfall)

1. Sketch the graph from the *Time Series Plot* of the rainfall for the schools using a different color for each school.
2. Estimate which school has the most rainfall.
3. Estimate which school has the least amount of rainfall.
4. If applicable, sketch a graph from the Time Series Plot of the snowfall for the schools using a different color for each school.
5. If any of the schools receive snowfall, which school receives the most snow? Which school receives the least amount of snow?
6. How do the schools compare in their amounts of snow?

Soil Moisture (30 cm)

1. Sketch the graph from the *Time Series Plot* of soil moisture for the schools, using a different color for each school.
2. Which schools have the wettest soil? Which schools have the driest soil?

Soil Data Extension

Soil scientists highly recommend the use of additional soil properties for ecosystem analysis of land cover. Soil characterization data can be obtained by retrieving the soil data archive for each school. Additional basic properties you can consider include slope, texture, structure, and pH. For advanced level analysis, you can consider nitrogen, phosphorus, and potassium measurements.

Using GLOBE Data to Analyze Land Cover

Data Gathering and Organizing Work Sheet-2

Geography and Topography

Creating a table of this information will help you to summarize this data so you can see likenesses and differences clearly.

Locate the schools on an atlas using the information on the *Basic Information Work Sheet* (latitude, longitude, and country).

1. On which continent is each school located?
2. Which schools, if any, are located near coastlines? Describe each school's direction from the coastline.
3. Which schools, if any, are located near large water bodies? Give the name of the water body and describe each school's direction from the water body.
4. Which schools, if any, are located near mountain ranges? Give the name of the mountain range(s) and describe each school's direction from the mountain range.
5. What is the direction of the prevailing winds for each area?
   a. Does the prevailing wind direction in any of the locations blow so it is likely to cross a mountain range?
   b. Does the prevailing wind blow directly in from the ocean before it comes to the school site?
   c. Does the prevailing wind blow across a large inland waterbody or dry land before it reaches the school sites?
6. Which schools, if any, are located in an area with an arid or wet climate? Indicate these schools and the type of climate.
7. Which schools, if any, are located in heavily urbanized areas?

Using GLOBE Data to Analyze Land Cover

Data Analysis Work Sheet-1

This section of the investigation is intended to help you learn how to analyze your data, summarize your results or findings, and interpret your findings to arrive at some conclusions. These may include new research questions or hypotheses. You will also have an opportunity to organize your new knowledge so you can present it for further discussion.

Answering these questions will help you apply the scientific method so you can learn a systematic approach for analyzing and making sense of data. This will help you to understand how the type of land cover in your school's GLOBE Study Area may be related to weather, climate, soils, and geographical location.

1. What are the temperature ranges (min-max), on average, for each of the schools?

2. Are there any patterns in these current temperature graphs for each school? Are the temperature patterns for each school similar? How are the patterns different?

3. Using an atlas, try to identify what the average temperature ranges might be in areas where your land cover class (MUC class) is found.

4. Analyze your rainfall graph.
   a. Identify the differences and similarities in total rainfall amounts for the period studied. Did all the schools receive the same amount? If not, what are the differences?

   b. Identify the patterns. When did rain fall? Were rain or storm events concentrated in a particular time period with dry periods, or was precipitation fairly evenly spread over the time period? In which locations did such patterns prevail?

   c. Make a table to compile this data so you can look at it and begin to think about what it might mean.

5. Using an atlas or climate database, identify what average rainfall is reported for similar land cover classes.

6. Do the schools' rainfall patterns differ from the average precipitation for their area? If so, are there deserts, mountains, or waterbodies between the area of prevailing winds and the schools?

7. If applicable, describe the snowfall graph and explain how the temperature affects snowfall.

8. If applicable, how does snowfall affect the land cover type for your school?

Using GLOBE Data to Analyze Land Cover

Data Analysis Work Sheet-2

9. What soil moisture patterns do you see for each school?

10. If precipitation events are not evenly distributed across the time period, what do the reported soil moisture data look like during and after these events?

11. Location.
    a. Are all the schools on the same continent? How far apart are they in degrees of latitude and longitude?

    b. Where are they in relation to the equator (include N or S of the equator in your description)?

    c. How much do they differ in elevation above sea level?

12. Which of the areas within the school sites or nearby are likely to have a MUC class that signifies developed land cover, especially urban (MUC 9)?

Answers to the above questions will represent your findings. Summarize these in a short paragraph. Attach the tables you created and refer to them in your summary to help explain your findings.

Conclusions - Project Report

What do your findings mean? What can we say about the relationship between the MUC class, temperature, precipitation, and soil moisture at the three school locations?

In a well organized report, use your data and data analysis to describe how the environmental parameter(s) of an ecosystem (temperature, precipitation and soil moisture) relate to the land cover type in that area. Formulate hypotheses about which environmental parameter(s) are the most important in determining the type of land cover in an area. Justify your answers using the data obtained in this activity.

Remember that your conclusions are based on the data you used.

Be sure to answer the following questions in your report.

- What do your data suggest about possible relationships between precipitation and soil moisture for the study sites?
- What do your data suggest about possible relationships between temperature and precipitation?
- Explain how the amount of soil moisture can influence the type and condition of the land cover.
- If you determined what the prevailing winds in the study areas were, how do you think these might affect precipitation, temperature, or both? Is this explanation likely to account for some differences in data among the study sites?
- What does your data tell you about topographic or other locational differences between the sites?
- How might these differences relate to temperature or precipitation patterns at the various sites?
- What does your data tell you about the likely conditions necessary to support the MUC land cover class which are at the three study sites?
- Are there any major differences in the amount of precipitation, temperature ranges, or soil moisture across the sites for the time period studied? If there were some differences, what hypothesis might explain these differences?
- If there are differences in the amount of precipitation, temperature ranges, or soil moisture across the sites, how could you explain why these areas have the same land cover type?
- How does your data compare with "average" data found in an atlas or other source for these geographic locations? How might local conditions in your study area (topography, location near a water body, direction of prevailing winds) account for the differences?
- What does your data tell you about the relationships between location, precipitation, soil moisture, temperature, and land cover class?
- Are there any questions you feel that you haven't been able to answer or new ideas (hypothesis) that might need further study to fully answer the above questions? If so, what are they? Do you think you might learn more about this relationship if you were able to compare data over a longer time period?

Some Ways To Share Your Results and Conclusions

- Display on a school bulletin board.
- Submit to the local newspaper.
- Use GLOBE mail to send your report to the other schools you studied.
- Submit to the Land Cover/Biology Team:

Dr. Russell Congalton and
Dr. Mimi Becker
215 James Hall
University of New Hampshire
Durham, NH, USA 03824

Adaptation

Graphing

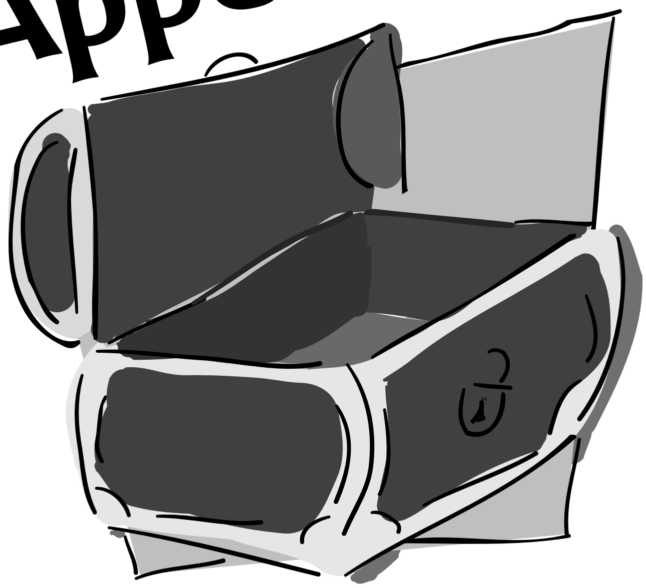
Instead of sketching the time series plots, students can use the actual GLOBE temperature, precipitation, and soil moisture data recorded by each school to create their own graphs. Following the instructions provided to create time series plots, you can retrieve the data for the schools and time period selected by selecting "**show table.**" It will show all the data reports of the selected parameter for the time period you selected. Scroll down to view the data table

Date YYYYMMDD	Jokiolnen deg C	Pagosa Springs deg C	Sonora deg C
19971101	7.0	--	--
19971102	6.0	--	--
19971103	6.0	--	--
19971104	-1.0	--	--
19971105	-3.0	21.0	--
19971106	-2.5	--	--
19971107	1.0	--	--
19971108	5.0	21.0	--
19971109	6.0	10.0	--
19971110	4.1	5.0	--
19971111	5.0	5.0	--
19971112	4.0	26.0	--
19971113	4.0	8.0	--
19971114	6.0	--	--
19971115	6.0	--	6.0
19971116	6.0	--	10.0
19971117	6.5	11.0	11.0

Acknowledgment

We acknowledge the following educators for evaluating this learning activity: George Duane, Frank Kelley, Patricia Gaudreau, Robert Schongalla, and Kathy Tafe.

Appendix



Clinometer Sheet

Table of Tangents

Table of Cosines

MUC Classification Practice Examples

Manual Mapping: A Tutorial for the Beverly, MA, Image

Accuracy Assessment Tutorial

Land Cover Sample Site Data Sheet

Canopy and Ground Cover Data Sheet

Graminoid, Tree, and Shrub Height Data Sheet

Alternative Clinometer Techniques Data Sheets

Tree Circumference Data Sheet

Graminoid Biomass Data Sheet

Accuracy Assessment Work Sheet

Fire Fuel Protocol: Center Plot Data Sheet

Fire Fuel Protocol: Transect Measurements Data Sheet

MUC System Glossary

Land Cover Glossary of Terms

Clinometer Sheet

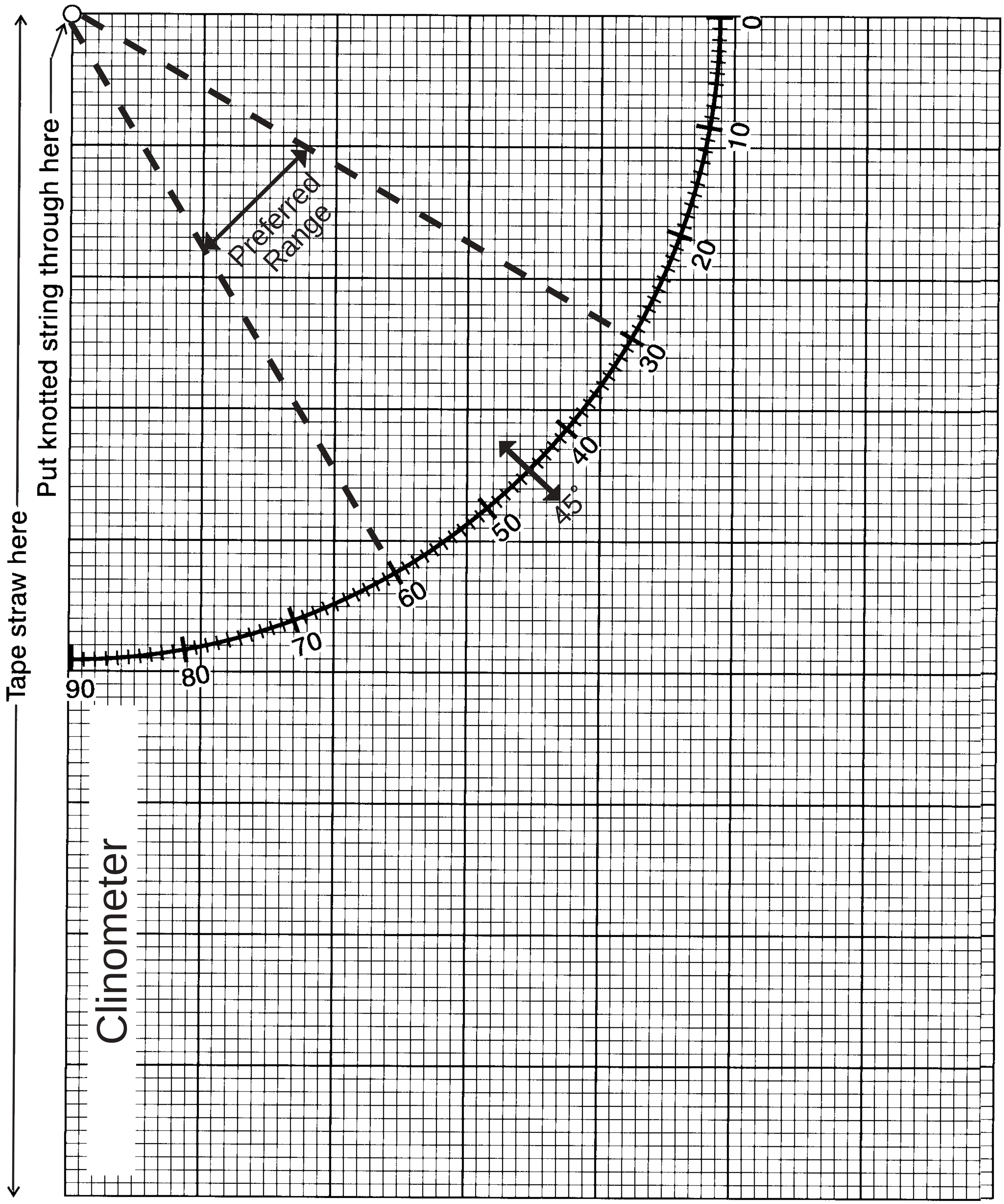


Table LAND-A-1: Table of Tangents

Angle	Tan.	Angle	Tan.	Angle	Tan.	Angle	Tan.	Angle	Tan.
1°	.02	17	.31	33	.65	49	1.15	65	2.14
2	.03	18	.32	34	.67	50	1.19	66	2.25
3	.05	19	.34	35	.70	51	1.23	67	2.36
4	.07	20	.36	36	.73	52	1.28	68	2.48
5	.09	21	.38	37	.75	53	1.33	69	2.61
6	.11	22	.40	38	.78	54	1.38	70	2.75
7	.12	23	.42	39	.81	55	1.43	71	2.90
8	.14	24	.45	40	.84	56	1.48	72	3.08
9	.16	25	.47	41	.87	57	1.54	73	3.27
10	.18	26	.49	42	.90	58	1.60	74	3.49
11	.19	27	.51	43	.93	59	1.66	75	3.73
12	.21	28	.53	44	.97	60	1.73	76	4.01
13	.23	29	.55	45	1.00	61	1.80	77	4.33
14	.25	30	.58	46	1.04	62	1.88	78	4.70
15	.27	31	.60	47	1.07	63	1.96	79	5.14
16	.29	32	.62	48	1.11	64	2.05	80	5.67

Example: Assume you have established a baseline distance of 60.0 meters. Assume that you have measured the tree top to an angle of 34°. From the Table, you will see that the tangent of 34° is 0.67. Therefore, the tree height above your eye height is 60.0 m x .67 = 40.2 meters. By adding your eye height above the ground (1.5 m), the total tree height is 41.7 meters.

Table LAND-AP-2: Table of Cosines

Not Part of Clinometer*

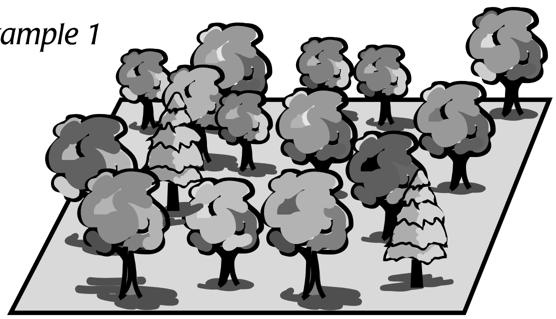
Angle	COS	Angle	COS	Angle	COS	Angle	COS	Angle	COS
1°	1.00	17	0.96	33	0.84	49	0.66	65	0.42
2	1.00	18	0.95	34	0.83	50	0.64	66	0.41
3	1.00	19	0.95	35	0.82	51	0.63	67	0.39
4	1.00	20	0.94	36	0.81	52	0.62	68	0.37
5	1.00	21	0.93	37	0.80	53	0.60	69	0.36
6	0.99	22	0.93	38	0.79	54	0.59	70	0.34
7	0.99	23	0.92	39	0.78	55	0.57	71	0.33
8	0.99	24	0.91	40	0.77	56	0.56	72	0.31
9	0.99	25	0.91	41	0.75	57	0.54	73	0.29
10	0.98	26	0.90	42	0.74	58	0.53	74	0.28
11	0.98	27	0.89	43	0.73	59	0.52	75	0.26
12	0.98	28	0.88	44	0.72	60	0.50	76	0.24
13	0.97	29	0.87	45	0.71	61	0.48	77	0.22
14	0.97	30	0.87	46	0.69	62	0.47	78	0.21
15	0.97	31	0.86	47	0.68	63	0.45	79	0.19
16	0.96	32	0.85	48	0.67	64	0.44	80	0.17

* For use with *Two-Triangle Alternative Technique to Measure Tree Height Field Guides*

MUC Classification Practice Examples

The following three examples provide students additional practice assigning MUC classes. In the first example, found in the MUC System section of the *Investigation Instruments,* students follow along step-by–step with the process. The three examples given below are for your students to try for themselves. Students should be able to accurately assign a MUC class by the time they complete the last example. Answers are at the bottom of each page. Student will need additional practice in the field in order to feel confident assigning MUC types but these examples will help students become familiar with the *MUC Field Guide* or *MUC System Table* and *MUC Glossary of Terms.*

MUC Classification Example 1



You perform your canopy cover and ground cover measurements, recording the number of times you saw vegetation through your densiometer and the number of times you saw sky. You calculate a canopy cover of 70% and note that the crowns of trees are not touching each other. From these data you know that the MUC Level 1 class is ______
(MUC)

____
(MUC Class Name)

Each time you see canopy vegetation through your densiometer, you also record and tally the tree type. It is 80% deciduous. This means that your MUC Level 1 and 2 class is ___ ___
(MUC)

____
(MUC Class Name)

There are not many climbers or epiphytes in this area and there are evergreens. There is a winter frost in the unfavorable season. This gives you a MUC Level 1, 2, and 3 class of ___ ___ ___
(MUC)

____
(MUC Class Name)

The evergreen trees have needle leaves. The complete MUC class is ___ ___ ___ ___, called
(MUC)

____
(MUC Class Name)

Answer: MUC 1222

MUC Classification Example 2

You live in a lowland temperate region. You select a land cover site that is mostly trees with the crowns touching each other, but about 20% of the ground area has houses on it. After measuring, the canopy is a 60% hemisclerophyllous evergreen and 40% deciduous mix.

Level 1: Look in the *MUC System Table* and check the Level 1 choices. When you think you have the Level 1 class, check the *MUC Glossary* to be sure. Write the answer in the correct space below.

Level 2: Look in the *MUC System Table* and check the Level 2 choices. There should only be a few. Reread the description given above and the definitions in the *MUC Glossary*. When you think you have the Level 2 class, write it below.

Level 3: Look in the *MUC System Table* and check the Level 3 choices. There should be quite a few, but look at them carefully, some will not fit your description at all. In reality, you will only have a few options again! Reread the description given above and the definitions in the *MUC Glossary*. When you think you have the Level 3 class, write it below.

Level 4: Look in the *MUC System Table* and check the Level 4 choices. There should only be a few. Reread the description given above and the definitions in the *MUC Glossary*. When you think you have the Level 4 class, write it below.

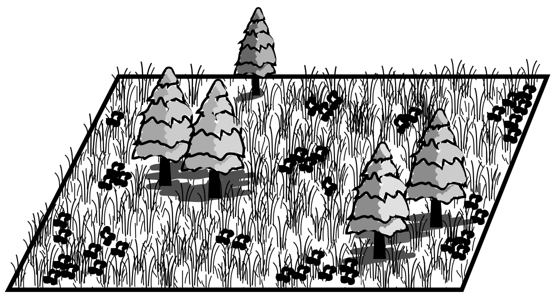
MUC Class _____ _____ _____ ____
Level 1 Level 2 Level 3 Level 4

____

(MUC Class Name)

Answer: MUC 0161

MUC Classification Example 3



After you perform your canopy and ground cover measurements, you calculate that the canopy cover is 20% and composed of a single species of pine tree (needle-leaved). Your ground cover is 90% herbaceous vegetation. It is composed of 85% graminoid and 15% forb. Most of the graminoid vegetation is over 3 meters tall.

What is the MUC class for this land cover sample site? ___ ___ ___ ___

____

(MUC Class Name)

Answer: MUC 4110

Manual Mapping

A Tutorial for the Beverly, MA, Image

The following tutorial is provided as an example of how a manual land cover map is made for the Beverly, MA Landsat Thematic Mapper (TM) image. After completing this tutorial as a training exercise, each step presented should also be done by your students, using the TM image of your own GLOBE Study Site (your 15 km x 15 km area.) Figure LAND-AP-1 shows a false-color infrared image of the Beverly, MA image, and will be used to illustrate the process of performing a manual land cover mapping. Note that water and vegetation types are more readily distinguished if the false-color infrared image is used. However, you also want to keep your "true-color" image handy, because it is useful for distinguishing developed areas.

The following steps are used in the manual mapping method.

1. Select the Landsat TM satellite image to be mapped. In the false-color infrared image, actively growing green vegetation will appear red (hardwoods and fields are bright red to pink, evergreens are dark red to black), water is black, while urban areas and bare soils are blue.
2. Overlay an 8.5 x 11 inch sheet of clear plastic on top of the colored print of the image, using tape to hold it firmly in place. Once the overlay is in place, mark the location of the image edges on the overlay so that it can be placed in exactly the same position if it is removed. This will also allow you to place the overlay on either the true color or false-color infrared image to take advantage of the discrimination capabilities of each type of image.
3. The mapping process involves carefully outlining the different land cover types seen on the image, using either colored crayons or felt-tip marking pens. Use different colors to represent different land cover classes if possible. Assign each the appropriate number for its specific MUC class. Be certain to identify each area with the most detailed MUC value for its class.

The illustrations accompanying this tutorial illustrate the steps in developing a manual land cover map. For clarity, the individual steps are shown on separate illustrations, then assembled to show the final map. In practice, each step is done on the same sheet, gradually building a complete map.

- Outline water bodies, as shown in Step 1. Here we see Marine Open Water, MUC 72, and Fresh Open Water, MUC 71. Note that for Open Water, the MUC scheme only contains two levels.
- In the illustration for Step 2, "Barren" areas, labeled MUC 52 (Sandy) and 53 (Bare Rock) are outlined. The Urban Residential (91) and Commercial (92) areas are also discriminated.
- In Step 3, the remaining major features are developed, including:

MUC 63 — Estuarine
MUC 93 — Urban Transportation
MUC 811 — Row Crops/Pasture
MUC 822 — Golf Courses
MUC 823 — Cemeteries

Also added are the vegetated areas:

MUC 0192 — Evergreen Temperate Closed Forest
MUC 0222 — Deciduous Closed Forest with Evergreens and Shrubs

- Step 4 presents the final product, a labeled land cover type map of the Beverly area. Your students should decide on the final format of your own map.

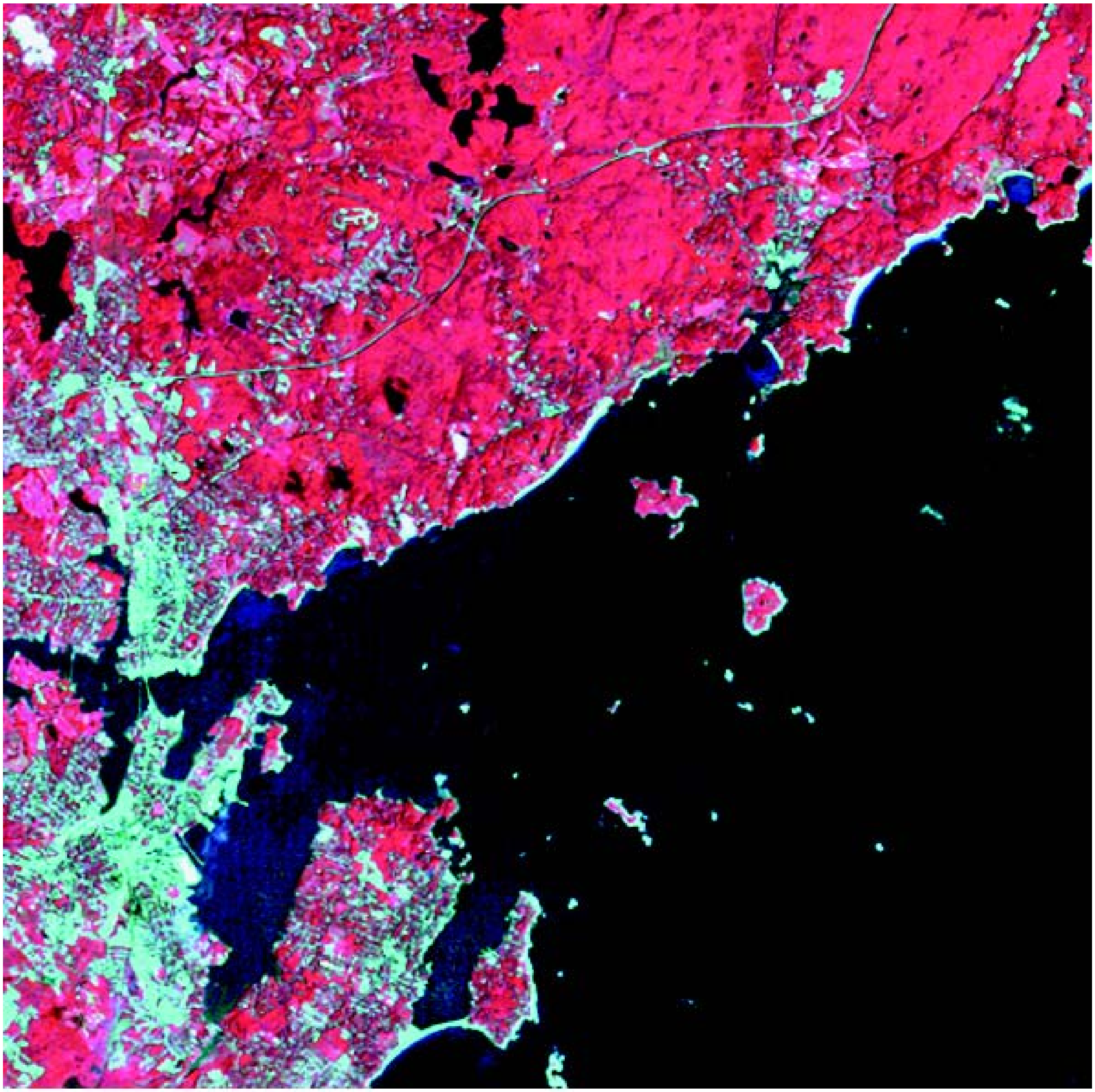
Since the land cover types in your local area may be very different from those in Beverly, MA, you may certainly want to proceed with a different order to outlining MUC classes. Remember to take advantage of both the true-color and false-color infrared images provided to your school.

If there are areas on your image for which your students are not sure of the specific MUC class, have students decide how they can verify what is in that location. This activity is likely to take several class periods to complete. Have your students be as careful and specific as possible in outlining and assigning classes to the various land cover areas in their image.

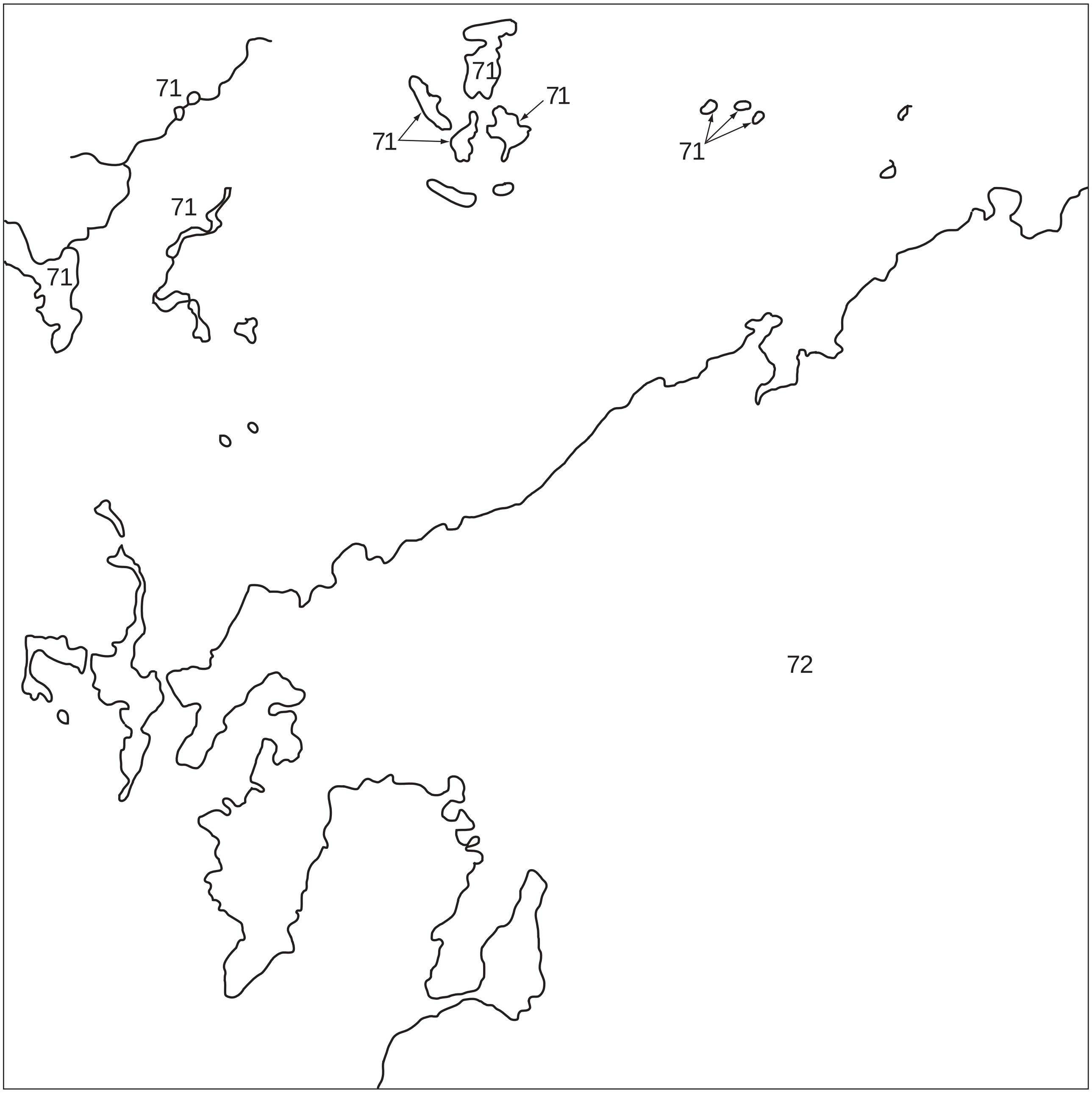
Once your Land Cover Map is completed, you will need to determine its accuracy. This is called "Accuracy Assessment," and is described in the *Accuracy Assessment Tutorial*.

During the validation process, you will report your validation data as Land Cover Sample Sites. Once your map is validated, a copy, along with your validation data, should be submitted to GLOBE by following the directions given in the *How to Submit Photos and Maps* section of the *Implementation Guide*.

Figure LAND-AP-1: Beverly Landsat Scene



Step 1



Step 2

Step 3


811
822
0222
0222
93
822
822
0192
63
0222
93
63
93
93
0222
93
823
93
822
822
93

Step 4

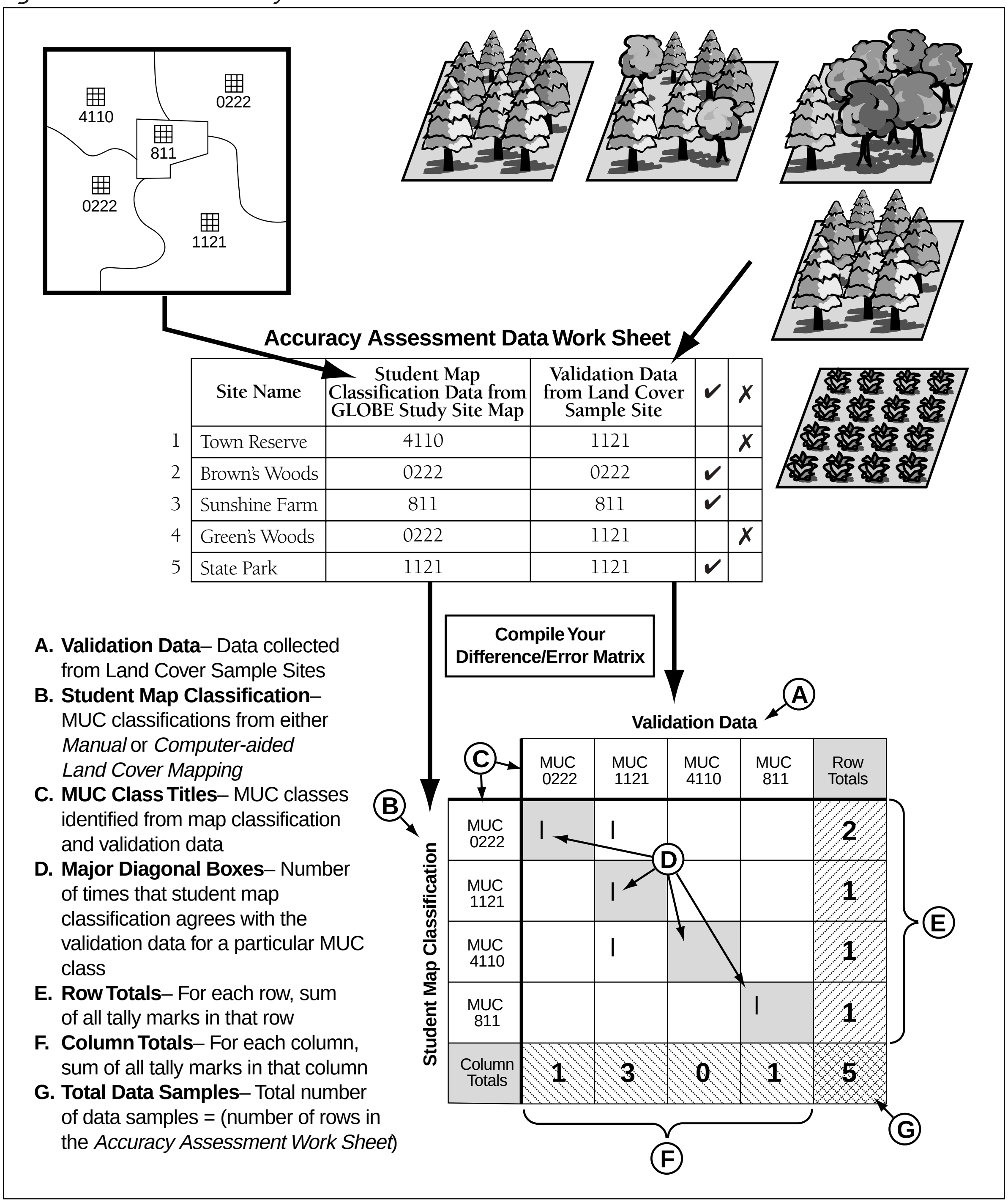

811
71
822
71
71
71
0222
53
0222
93
71
92
822
822
0192
91
93
0222
91
71
93
91
52
93
63
0222
93
52
52
91
823
93
52
822
91
52
92
52
72
91
92
91
93
92
91
91
52

Accuracy Assessment Tutorial

After you make a land cover type map by using the *Manual* or *Computer-aided Land Cover Mapping Protocol* and collect many Land Cover Sample Site data, you are ready to assess the accuracy of your map. Use this Accuracy Assessment Tutorial as a guide. There is also an example *Accuracy Assessment Work Sheet* so you can practice first.

Figure LAND-AP-2 illustrates the map making and accuracy assessment process. First, students collect land cover sample site data and make a land cover map. Then, the student map data and the validation data (from additional Land Cover Sample Sites) are compared in an *Accuracy Assessment Work Sheet*. Finally, the data are compiled in a difference/error matrix. Using this matrix, accuracy assessment percentages can be calculated.

Figure LAND-AP-2: Accuracy Assessment Process



There are several accuracy assessment percentages that can be calculated. They are defined below.

Accuracy Assessment Percentages

Overall Accuracy indicates how well the map identifies all land cover types on the ground.

Producer's Accuracy indicates what percentage of the time a particular land cover type on the ground was identified as that land cover type on the map. It expresses how well the map producer identified a land cover type on the map from the satellite imagery data.

User's Accuracy indicates what percentage of the time a particular land cover type on the map is really that land cover type on the ground. It expresses how well a person using the map will find that land cover type on the ground.

Helpful Hints:

- There are two options for students depending on ability level. Younger students can enter the data from the *Accuracy Assessment Work Sheet* onto the GLOBE Web site and it will produce the Difference/Error Matrix, Overall Accuracy, Producer's and User's Accuracy for them. For older students or a more math-oriented class, students can follow the *Accuracy Assessment Tutorial* and create the matrix from the *Accuracy Assessment Work Sheet*. After they have entered the data into the GLOBE Web site, they can compare their results to the ones generated by GLOBE.
- The accuracy assessment can be repeated when more validation data have been collected. The statistical validity of the accuracy assessment matrix improves as more samples are used.
- An accuracy assessment can be performed on only a portion of the map.
- **Land Cover Sample Site data, which were not used in the development of the map, are used to create the difference/error matrix.**
- Some of the error in a map made from satellite imagery may be related to the fundamental limitation of the satellite image data as a tool in distinguishing land cover classes.
- Ideally, you should have validation samples for every type of land cover in your GLOBE Study Site. It may be desirable to only generate the matrix for the 3-5 most common land cover types.
- Collecting validation data is a time consuming process. It may take numerous classes to put together enough data for a valid matrix.
- Create and rely on your GLOBE learning community to gather enough data for this protocol.
- You can use the *Sample Completed Accuracy Assessment Work Sheet* for extra practice.
- Doing the *Bird Beak Accuracy Assessment Learning Activity* will help you prepare for this tutorial.

Completed *Accuracy Assessment Work Sheet*

	Site Name	Student Map Classification Data from GLOBE Study Site	Validation Data from Land Cover Sample Site	✔	✗
1	Town Reserve	4110	1121		✗
2	Brown's Woods	0222	0222	✔	
3	Sunshine Farm	811	811	✔	
4	Green's Woods	0222	1121		✗
5	State Park	1121	1121	✔	

The first time through this tutorial, use the Completed *Accuracy Assessment Work Sheet* above to follow the steps.

What You Need

- Landsat TM satellite images of the GLOBE Study Site
- Your student classified land cover map
- MUC data from Land Cover Sample Sites
- *Accuracy Assessment Work Sheet*
- *Accuracy Assessment Tutorial*
- Pen or pencil
- Blank paper
- Calculator (optional)
- Ruler/straight edge (optional)

What To Do

1. Complete the *Accuracy Assessment Work Sheet.*

a. Gather the MUC validation data if it has not already been organized for you.

b. Fill in the *Accuracy Assessment Work Sheet* using the MUC data and your student classified land cover map.

1. Find a land cover type on your map, write the name of the area and its MUC code classification on the *Accuracy Assessment Work Sheet.*
2. Look through the validation data (Land Cover Sample Site data) to find the MUC classification you recorded when you visited the site. Record this MUC on the *Accuracy Assessment Work Sheet.*
3. Repeat this process (Steps 1 and 2) until you have covered every area on your student classified land cover map.

c. Complete the table by putting a "✔" when the two MUC classes agree and a "✘" when they do not.

2. Build an empty difference/error matrix.

a. There should be a column and row in the matrix for every MUC Class that occurs on your *Accuracy Assessment Work Sheet.*

b. Add two extra rows and two extra columns for the titles and totals.

Note: The example difference/error matrix is shaded to help show the titles, totals, and data in agreement. There is no need to shade your matrix.

	MUC	MUC	MUC	MUC	
MUC					
MUC					
MUC					
MUC					

3. Label Your Difference/Error Matrix with Titles and MUC Classes

a. Label the top, "Validation Data."

b. Label the left side, "Student Map Classification."

c. Label the columns and rows of the difference/error matrix with your MUC classes from the *Accuracy Assessment Work Sheet.* Put the MUC classes in the same order from the upper left-hand corner going down (row titles) and across (column titles).

Note: The MUC classes in your matrix may be different. This matrix was created using the example *Accuracy Assessment Work Sheet* on the previous page.

d. Label the last row "Column Totals."

e. Label the last column, "Row Totals."

		Validation Data				
		MUC 0222	MUC 1121	MUC 4110	MUC 811	Row Totals
Student Map Classification	MUC 0222					
	MUC 1121					
	MUC 4110					
	MUC 811					
	Column Totals					

4. Tally each row of data from the completed *Accuracy Assessment Work Sheet.*

a. Find the row in your matrix matching the Student Map Classification MUC Class.

E.g., In the first row of the completed *Accuracy Assessment Work Sheet*, the Student Map Classification MUC class is 4110.

Validation Data

Student Map Classification	MUC 0222	MUC 1121	MUC 4110	MUC 811	Row Totals
MUC 0222					
MUC 1121					
MUC 4110					
MUC 811					
Column Totals					

b. Find the column in your matrix matching the Validation Data MUC Class.

E.g., In the first row of the completed *Accuracy Assessment Work Sheet*, the Validation Data MUC Class is 1121.

Validation Data

Student Map Classification	MUC 0222	MUC 1121	MUC 4110	MUC 811	Row Totals
MUC 0222					
MUC 1121					
MUC 4110					
MUC 811					
Column Totals					

c. Put a tally mark (I) in the box where the row and column overlap.

Validation Data

Student Map Classification	MUC 0222	MUC 1121	MUC 4110	MUC 811	Row Totals
MUC 0222					
MUC 1121					
MUC 4110		I			
MUC 811					
Column Totals					

d. Repeat these steps to tally all the rows of data in your *Accuracy Assessment Work Sheet.*

Validation Data

Student Map Classification	MUC 0222	MUC 1121	MUC 4110	MUC 811	Row Totals
MUC 0222	I	I			
MUC 1121		I			
MUC 4110		I			
MUC 811				I	
Column Totals					

5. Calculate Totals

a. ***Calculate Row Totals*** **–** For each row, add up all tally marks in the row and put that value in the ***Row Total*** box for that row.

Validation Data

Student Map Classification	MUC 0222	MUC 1121	MUC 4110	MUC 811	Row Totals
MUC 0222	I	I			2
MUC 1121		I			
MUC 4110		I			
MUC 811				I	
Column Totals					

b. ***Calculate Column Totals*** **–** For each column, add up all tally marks in the column and put that value in the ***Column Total*** box for that column.

Validation Data

Student Map Classification	MUC 0222	MUC 1121	MUC 4110	MUC 811	Row Totals
MUC 0222	I	I			2
MUC 1121		I			1
MUC 4110		I			1
MUC 811				I	1
Column Totals	1				

c. Total Data Samples

Add up the *Row Totals* boxes. 2 + 1 + 1 + 1 = 5

Add up the *Column Totals* boxes. 1 + 3 + 0 + 1 = 5

The sum of the column totals should equal the sum of the row totals. This should be equal to the total number of data samples (rows) on your *Accuracy Assessment Work Sheet*.

Put this number in the bottom right box (where *Row Totals* and *Column Totals* overlap).

If the sum of the row totals does not equal the sum of the column totals, recheck your math and tallies.

Validation Data

Student Map Classification	MUC 0222	MUC 1121	MUC 4110	MUC 811	Row Totals
MUC 0222	I	I			2
MUC 1121		I			1
MUC 4110		I			1
MUC 811				I	1
Column Totals	1	3	0	1	5

6. Calculate the Accuracy Assessment Percentages

a. *Calculate Overall Accuracy*

$$\text{Overall Accuracy} = \frac{\text{sum of major diagonal tallies}}{\text{total number of samples}} \times 100$$

Add the tallies in all the boxes on the major diagonal (shaded) of your matrix except the lower right-hand *Total* box. Divide this sum by the total number of samples (the value in the lower right-hand *total* box). Multiply by 100 to convert it to a percentage.

$$\text{Overall Accuracy} = \frac{(1 + 1 + 0 + 1)}{5} \times 100 = 60\%$$

Validation Data

Student Map Classification	MUC 0222	MUC 1121	MUC 4110	MUC 811	Row Totals
MUC 0222	I	I			2
MUC 1121		I			1
MUC 4110		I			1
MUC 811				I	1
Column Totals	1	3	0	1	5

b. *Calculate User's Accuracy*

$$\text{User's Accuracy} = \frac{\text{\# correctly identified}}{\text{Row Total}} \times 100$$

For each MUC class, divide the number of times you correctly identified it (value on major diagonal) by the Row Total for that MUC Class.

E.g., User's Accuracy = $^1/_2$ X 100 = 50% for MUC 0222

Validation Data

Student Map Classification	MUC 0222	MUC 1121	MUC 4110	MUC 811	Row Totals
MUC 0222	I	I			2
MUC 1121		I			1
MUC 4110		I			1
MUC 811				I	1
Column Totals	1	3	0	1	5

c. *Calculate Producer's Accuracy*

$$\text{Producer's Accuracy} = \frac{\text{\# correctly identified}}{\text{Column Total}} \times 100$$

For each MUC class, divide the number of times you correctly identified it (value on major diagonal) by the Column Total for that MUC Class.

E.g., Producer's Accuracy = $^1/_1$ X 100 = 100% for MUC 0222

Validation Data

Student Map Classification	MUC 0222	MUC 1121	MUC 4110	MUC 811	Row Totals
MUC 0222	I	I			2
MUC 1121		I			1
MUC 4110		I			1
MUC 811				I	1
Column Totals	1	3	0	1	5

For more practice:

Sample Completed *Accuracy Assessment Work Sheet*

	Site Name	Student Map Classification Data from GLOBE Study Site	Validation Data from Land Cover Sample Sites	✔	✗
1	Woodward's Valley	0222	1222		✗
2	Bunyan Trail Woodland	4213	1222		✗
3	State Forest Land	0222	0222	✔	
4	The Woods North of School	1222	1222	✔	
5	Brer's Preserve	2231	2231	✔	
6	Shrubland East of Gravel	1222	2231		✗
7	Nature Conservancy Land	2231	62		✗
8	Janice Denver's Property	4233	4213		✗
9	Moosehead Hill	4233	4233	✔	
10	Wetland Behind Food Store	2231	62		✗
11	The Gravel Mine	56	56	✔	
12	Calypso Lake	71	71	✔	
13	Junior's Farm	811	811	✔	
14	St. Augustine Farm	811	811	✔	
15	Johann's Neighborhood	91	91	✔	

MUC Class List

0222 – Closed Forest, Mainly Deciduous, Cold-Deciduous with Evergreens, With Evergreen Needle-Leaved Trees
1222 – Woodland, Mainly Deciduous, Cold-Deciduous with Evergreens, With Evergreen Needle-Leaved Trees
2231 – Shrubland or Thicket, Mainly Deciduous, Cold-Deciduous, Temperate
4213 – Herbaceous Vegetation, Medium Tall Graminoid, With Trees Covering 10-40%, Trees: Broad-Leaved Deciduous
4223 – Herbaceous Vegetation, Medium Tall Graminoid, With Trees Covering <10%, Trees: Broad-Leaved Deciduous
4233 – Herbaceous Vegetation, Medium Tall Graminoid, With Shrubs, Shrubs: Broad-Leaved Deciduous
4313 – Herbaceous Vegetation, Short Graminoid, With Trees Covering 10-40%, Trees: Broad-Leaved Deciduous
56 – Barren Land, Other
62 – Wetland, Palustrine
71 – Open Water, Freshwater
811 – Cultivated Land, Agriculture, Row Crop and Pasture
823 – Cultivated Land, Non-Agriculture, Cemeteries
91 – Urban, Residential

Difference/Error Matrix for
"Sample Completed Accuracy Assessment Work Sheet"

Validation Data

Student Map Classification

	MUC 0222	MUC 1222	MUC 2231	MUC 4213	MUC 4233	MUC 56	MUC 62	MUC 71	MUC 811	MUC 91	Row Totals
MUC 0222	I	I									**2**
MUC 1222		I	I								**2**
MUC 2231			I				II				**3**
MUC 4213		I									**1**
MUC 4233				I	I						**2**
MUC 56						I					**1**
MUC 62											**0**
MUC 71								I			**1**
MUC 811									II		**2**
MUC 91										I	**1**
Column Totals	**1**	**3**	**2**	**1**	**1**	**1**	**2**	**1**	**2**	**1**	**15**

Accuracy Assessment Percentages for *"Sample Completed Accuracy Assessment Work Sheet"*

Overall Accuracy
9 ÷ 15 x 100 = 60%

User's Accuracies

MUC Class	Calculation	User's Accuracy
0222	1 ÷ 2 x 100	50%
1222	1 ÷ 2 x 100	50%
2231	1 ÷ 3 x 100	33%
4213	0 ÷ 1 x 100	0%
4233	1 ÷ 2 x 100	50%
56	1 ÷ 1 x 100	100%
62	0	NA
71	1 ÷ 1 x 100	100%
811	2 ÷ 2 x 100	100%
91	1 ÷ 1 x 100	100%

Producer's Accuracies

MUC Class	Calculation	Producer's Accuracy
0222	1 ÷ 1 x 100	100%
1222	1 ÷ 3 x 100	33%
2231	1 ÷ 2 x 100	50%
4213	0 ÷ 1 x 100	0%
4233	1 ÷ 1 x 100	100%
56	1 ÷ 1 x 100	100%
62	0 ÷ 2 x 100	0%
71	1 ÷ 1 x 100	100%
811	2 ÷ 2 x 100	100%
91	1 ÷ 1 x 100	100%

Questions for Further Investigation

- What could you do to improve your overall accuracy?
- How accurate is your map if someone wanted to find a good place to have a picnic in the woods?
- How accurate is your map if you wanted to see how many times you correctly identified a park or playing field?
- Which were better – your producer's or user's accuracies? Why do you think that is?
- How could next year's class use your data to create a better Student Classified Map?

Land Cover Investigation

Sample Site Data Sheet

School Name: ____

Measurement Time: ____
Year Month Day Hour (UT)

Recorded By: ____________________ ______________________________

LOCATION

Site Name: ____

City/State/Country: ____

Locational Data: Source: ☐ **GPS** ☐ **Other** ______________________________

For GPS data, record from *GPS Investigation Data Sheet* or *Offset Data Sheet*

Latitude		Longitude		Elevation
________ decimal degrees		________ decimal degrees		________ meters
☐ North	☐ South	☐ East	☐ West	

MUC TO THE MOST DETAILED LEVEL

MUC Class: ____ ____ ____ ____

MUC Land Cover Type Name: ____

____

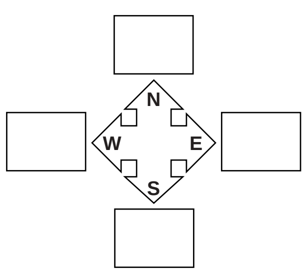
METADATA (Comments)

____

____

____

PHOTO NUMBER AND ORIENTATION



Land Cover Investigation

Canopy and Ground Cover Data Sheet*

School Name: ______________________ Site: ______________________

Measurement Time: ______________________
Year Month Day Hour (UT)

Recorded By: ______________________

	1. **Canopy Observations** T = Tree Canopy SB = Shrub Canopy – = Sky	2. **Canopy Type** E = Evergreen D = Deciduous – = Sky	3. **Ground Observations** G = Green Cover B = Brown Cover – = No Cover	4. **Ground Vegetation Type** GD = Graminoid FB = Forb OG = Other Green Veg. SB = Shrub DS = Dwarf-Shrub	5. **Canopy Species or Common Name**	6. **Shrub Cover** + = Tallest vegetation is a shrub – = All other	7. **Dwarf Shrub Cover** + = Tallest vegetation is a dwarf shrub – = All other
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							

	1. **Canopy Observations** T = Tree Canopy SB = Shrub Canopy – = Sky	2. **Canopy Type** E = Evergreen D = Deciduous – = Sky	3. **Ground Observations** G = Green Cover B = Brown Cover – = No Cover	4. **Ground Vegetation Type** GD = Graminoid FB = Forb OG = Other Green Veg. SB = Shrub DS = Dwarf-Shrub	5. **Canopy Species or Common Name**	6. **Shrub Cover** + = Tallest vegetation is a shrub – = All other	7. **Dwarf Shrub Cover** + = Tallest vegetation is a dwarf shrub – = All other
26							
27							
28							
29							
30							
31							
32							
33							
34							
35							
36							
37							
38							
39							
40							

Summary of Tree Canopy Observations	
Total “T”	
Total “–”	
Total Observations	
% Tree Canopy	

Summary of Canopy Type	
Total “E”	
Total “D”	
Total Observations	
% Evergreen (E)	
% Deciduous (D)	

Summary of Ground Observations	
Total “G”	
Total “B”	
Total “–”	
Total Observations	
% Ground	

Summary of Ground Vegetation Type	
Total “GD”	
Total “FB”	
Total “OG”	
Total “SB”	
Total “DS”	
Total Observations	
% Graminoid (GD)	
% Forb (FB)	
% Other Green (OG)	

Summary of Shrub Cover	
Total “+” in col. 6	
Total Observations	
% of Shrub Cover	

Summary of Dwarf Shrub Cover	
Total “+” in col. 7	
Total Observations	
% of Dwarf Shrub Cover	

Land Cover Investigation

Graminoid, Tree and Shrub Height Data Sheet

School Name: ______________________ Site: ______________________

Measurement Time: ______________________
Year Month Day Hour (UT)

Recorded By: ______________________

Clinometer Data

*Dominant Species ________ ________	Clinometer Reading (°)	TAN of Clinometer Reading	Distance from Tree (m)	Eye Height (m)	*Vegetation Height (m)	*Average Height (m)
Specimen 1.						
Specimen 2.						
Specimen 3.						
Specimen 4.						
Specimen 5.						

*Co-Dominant Species ________ ________	Clinometer Reading (°)	TAN of Clinometer Reading	Distance from Tree (m)	Eye Height (m)	*Vegetation Height (m)	*Average Height (m)
Specimen 1.						
Specimen 2.						
Specimen 3.						
Specimen 4.						
Specimen 5.						

Tree Height = (TAN of Clinometer Reading x Distance from Tree) + Eye Height

Note: Measure each tree three times and average the three height values. If all three values are within 1 meter of the average, report the values. If not, repeat the measurements until they are within 1 meter of their average, and then report these values.

* Use these columns for measuring the height of graminoids, shrubs, and dwarf-shrubs. Use all the columns if you use your clinometer to measure height.

Land Cover Investigation

Measure Tree Height on Level Ground: Simplified Clinometer Technique Data Sheet

School Name: ______________________ Site: ______________________

Measurement Time: ______________________
Year Month Day Hour (UT)

Recorded By: ______________________

Clinometer Data

Dominant Species ______________ ______________	Clinometer Reading (˚)	Tree Height (m) (Distance from Base of Tree (m)and Up to Eyes)	Average Tree Height (m)
Specimen 1.	45˚		
Specimen 2.	45˚		
Specimen 3.	45˚		
Specimen 4.	45˚		
Specimen 5.	45˚		

Co-Dominant Species ______________ ______________	Clinometer Reading (˚)	Tree Height (m) (Distance from Base of Tree (m)and Up to Eyes)	Average Tree Height (m)
Specimen 1.	45˚		
Specimen 2.	45˚		
Specimen 3.	45˚		
Specimen 4.	45˚		
Specimen 5.	45˚		

Note: Measure each tree three times and average the three height values. If all three values are within 1 meter of the average, report the values. If not, repeat the measurements until they are within 1 meter of their average, and then report these values.

Land Cover Investigation

Measure Tree Height on a Slope: Stand by Tree Data Sheet

School Name: ________________________ Site: ____________________

Measurement Time: ____
Year Month Day Hour (UT)

Recorded By: ____

Clinometer Data

Dominant Species ____________ ____________	Clinometer Reading (°)	TAN of Clinometer Reading	Height to 0° on Tree (m)	Distance to Tree (m)	Tree Height (m)	Average Tree Height (m)
Specimen 1.						
Specimen 2.						
Specimen 3.						
Specimen 4.						
Specimen 5.						

Co-Dominant Species ____________ ____________	Clinometer Reading (°)	TAN of Clinometer Reading	Height to 0° on Tree (m)	Distance to Tree (m)	Tree Height (m)	Average Tree Height (m)
Specimen 1.						
Specimen 2.						
Specimen 3.						
Specimen 4.						
Specimen 5.						

Tree Height = [(TAN of Clinometer Reading) x (Distance to Tree)] + (Height to 0° on Tree)

Note: Measure each tree three times and average the three height values. If all three values are within 1 meter of the average, report the values. If not, repeat the measurements until they are within 1 meter of their average, and then report these values.

Land Cover Investigation

Measure Tree Height on a Slope: Two-Triangle with Feet Higher than Tree Base Technique Data Sheet

School Name: ______________________ Site: ______________________

Measurement Time: ______________________
Year Month Day Hour (UT)

Recorded By: ______________________

Clinometer Data

Dominant Species ________	1st Clinometer Reading (˚)	TAN of 1st Clinometer Reading	2nd Clinometer Reading (˚)	TAN of 2nd Clinometer Reading	3rd Clinometer Reading (˚)	COS of 3rd Clinometer Reading	Distance to the Tree (m)	Baseline Calculation (m)	Tree Height (m)	Average Tree Height (m)
Specimen 1.										
Specimen 2.										
Specimen 3.										
Specimen 4.										
Specimen 5.										

Baseline = (Distance to the Tree) x (COS of 3rd Clinometer Reading)

Tree Height = [(TAN of 1st Clinometer Reading) x (Baseline)] + [(TAN of 2nd Clinometer Reading) x (Baseline)]

Note: Measure each tree three times and average the three height values. If all three values are within 1 meter of the average, report the values. If not, repeat the measurements until they are within 1 meter of their average, and then report these values.

Land Cover Investigation

Measure Tree Height on a Slope: Two-Triangle with Feet Higher than Tree Base Technique Data Sheet – Page 2

School Name: ______________________ Site: ______________________

Measurement Time: ______________________
Year Month Day Hour (UT)

Recorded By: ______________________

Clinometer Data

Co-Dominant Species	1st Clinometer Reading (°)	TAN of 1st Clinometer Reading	2nd Clinometer Reading (°)	TAN of 2nd Clinometer Reading	3rd Clinometer Reading (°)	COS of 3rd Clinometer Reading	Distance to the Tree (m)	Baseline Calculation (m)	Tree Height (m)	Average Tree Height (m)
Specimen 1.										
Specimen 2.										
Specimen 3.										
Specimen 4.										
Specimen 5.										

Baseline = (Distance to the Tree) x (COS of 3rd Clinometer Reading)

Tree Height = [(TAN of 1st Clinometer Reading) x (Baseline)] + [(TAN of 2nd Clinometer Reading) x (Baseline)]

Note: Measure each tree three times and average the three height values. If all three values are within 1 meter of the average, report the values. If not, repeat the measurements until they are within 1 meter of their average, and then report these values.

Land Cover Investigation

Measure Tree Height on a Slope: Two-Triangle with Feet Lower than Tree Base Technique Data Sheet

School Name: ______________________ Site: ______________________

Measurement Time: ______________________
Year Month Day Hour (UT)

Recorded By: ______________________

Clinometer Data

Dominant Species	1st Clinometer Reading (˚)	TAN of 1st Clinometer Reading	2nd Clinometer Reading (˚)	TAN of 2nd Clinometer Reading	3rd Clinometer Reading (˚)	COS of 3rd Clinometer Reading	Distance to the Tree (m)	Baseline Calculation (m)	Tree Height (m)	Average Tree Height (m)
Specimen 1.										
Specimen 2.										
Specimen 3.										
Specimen 4.										
Specimen 5.										

Baseline = (Distance to the Tree) x (COS of 3rd Clinometer Reading)

Tree Height = [(TAN of 1st Clinometer Reading) x (Baseline)] – [(TAN of 2nd Clinometer Reading) x (Baseline)]

Note: Measure each tree three times and average the three height values. If all three values are within 1 meter of the average, report the values. If not, repeat the measurements until they are within 1 meter of their average, and then report these values.

Land Cover Investigation

Measure Tree Height on a Slope: Two-Triangle with Feet Lower than Tree Base Technique
Data Sheet – Page 2

School Name: ______________________ Site: ______________________

Measurement Time: ____
Year Month Day Hour (UT)

Recorded By: ____

Clinometer Data

Co-Dominant Species	1st Clinometer Reading (°)	TAN of 1st Clinometer Reading	2nd Clinometer Reading (°)	TAN of 2nd Clinometer Reading	3rd Clinometer Reading (°)	COS of 3rd Clinometer Reading	Distance to the Tree (m)	Baseline Calculation (m)	Tree Height (m)	Average Tree Height (m)
Specimen 1.										
Specimen 2.										
Specimen 3.										
Specimen 4.										
Specimen 5.										

Baseline = (Distance to the Tree) x (COS of 3rd Clinometer Reading)

Tree Height = [(TAN of 1st Clinometer Reading) x (Baseline)] – [(TAN of 2nd Clinometer Reading) x (Baseline)]

Note: Measure each tree three times and average the three height values. If all three values are within 1 meter of the average, report the values. If not, repeat the measurements until they are within 1 meter of their average, and then report these values.

Land Cover Investigation
Tree Circumference Data Sheet

School Name: ______________________________ Site: ________________________

Measurement Time: ____
Year Month Day Hour (UT)

Recorded By: ____

Tree Circumference Measurements

Dominant Species:	Tree circumference (cm)
1.	
2.	
3.	
4.	
5.	

Co-Dominant Species:	Tree circumference (cm)
1.	
2.	
3.	
4.	
5.	

Land Cover Investigation

Graminoid Biomass Data Sheet

School Name: ______________________ Site: ______________________

Measurement Time: ______________________
Year Month Day Hour (UT)

Recorded By: ______________________

Graminoid Biomass Measurements

Sample Number	Color	Mass of Sample and Bag (g)	Mass of Empty Bag (g)	Graminoid Biomass (g)
1.	Green			
	Brown			
2.	Green			
	Brown			
3.	Green			
	Brown			

Graminoid Biomass = Mass of Sample and Bag – Mass of Empty Bag

Accuracy Assessment

Work Sheet

For Students

	Site Name	Student Map Classification from GLOBE Study Site	Validation Data from Land Cover Sample Sites	✔	✗
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					

Fire Fuel Protocol

Center Plot Data Sheet

School Name: ______________________________

Observer Names: ______________________________

Date: ____________ Study Site Name (give your site a unique name): ____________

Aspect: ____________ degrees True North (enter 0 for sites with no slope)

Overall slope of stand: looking up ________slope degrees looking down ________slope degrees

Heights of trees or shrubs in dominant stratum:

Tree or Shrub	Height(m)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Average height of dominant stratum = (sum of heights) ÷ (total number of trees and shrubs)

Average height: ____________

Heights of the base of crowns in lowest stratum:

Tree or Shrub	Height(m)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Average height of base of crowns = (sum of heights) ÷ (total number of trees and shrubs)

Average height: ________

Comments: ______________________________

Fire Fuel Protocol:
Transect Measurements Data Sheet

School Name: ____________________

Observer Names: ____________________

Date: __________ Study Site Name (give your site a unique name): __________

Number of Transects: __________

Woody Fuel Counts

	Transect 1	Transect 2	Transect 3	Transect 4
Direction of transect (True North)	90°	330°	270°	210°
Slope of transect (degrees)				
0-1 cm diameters (5-7 m mark)				
1-3 cm diameters (5-10 m mark)				
3-8 cm diameters (5-25 m mark)				

	Transect 5	Transect 6	Transect 7
Direction of transect (True North)	150°	90°	30°
Slope of transect (degrees)			
0-1 cm diameters (5-7 m mark)			
1-3 cm diameters (5-10 m mark)			
3-8 cm diameters (5-25 m mark)			

MUC Glossary of Terms

This glossary provides definitions, decision criteria, and examples for the land cover types outlined in the Modified UNESCO Classification (MUC) System. The land cover types are organized numerically in the same order as the classes appear in the MUC System Table. Miscellaneous terms used in the glossary are defined in the section following the numbered MUC definitions.

The MUC Glossary of Terms contains four columns of information:

1. **MUC Class** – the number used to classify each land cover type.
2. **MUC Name** – the name used to describe each land cover type.
3. **MUC Level** – the hierarchical level of the MUC System for each MUC Class from 1 (general classes) to 4 (detailed classes).
4. **Definitions** – definitions, decision criteria, and examples used to define each MUC Class.

References

A land use and land cover classification system for use with remote sensor data. J.R. Anderson, E.E. Hardy, J.T. Roach, and R.E. Witmer. U.S. Geol. Surv. Professional Paper, 1976.

The Atmosphere: An Introduction to Meteorology, 6th Ed. Lutgens, Fredrick K. & Tarbuck, Edward J. Englewood Cliffs, NJ: Prentice Hall, Inc., 1995.

Biology of Plants, 5th Ed. Raven, Peter H., Evert, Ray F., & Eichhorn, Susan E. New York, NY: Worth Publishers, 1992.

Classification of wetlands and deepwater habitats of the United States. L.M. Cowardin, V. Carter, F.C. Golet, and E.T. LaRoe. U.S. Fish and Wildlife Service. FWS/OBS-79/31, 1979.

International classification and mapping of vegetation. United Nations Educational, Scientific and Cultural Organization. Switzerland: UNESCO, 1973.

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MUC (Modified UNESCO Classification) System Glossary

MUC Class	MUC Name	MUC Level	Definitions
0	**Closed Forest**	**level 1**	**Formed by trees at least 5 meters tall with their crowns (i.e. branches) interlocking. The tree canopy covers at least 40% of the ground.**
01	Mainly Evergreen	level 2	Within *Closed Forest* (0). The canopy is never without green foliage. At least 50% of the trees that reach the canopy are evergreen. Individual trees may shed their leaves.
011	Tropical Wet (Rain)	level 3	Within *Mainly Evergreen Closed Forest* (01). Often called a tropical rain forest. Consisting mainly of broad-leaved evergreen trees, neither cold nor drought resistant. Truly evergreen, i.e. the forest canopy remains green all year though a few individual trees may be leafless for a few weeks. Leaves of many species have “drip tips.”
0111	Lowland	level 4	Within *Tropical Wet Mainly Evergreen Closed Forest* (011). Consists usually of numerous species of fast growing trees, many exceeding 50 meters tall, generally with smooth, often thin bark, some with buttresses. Emergent trees or at least a very uneven canopy often present. Undergrowth is sparse, composed mainly of tree seedlings. Palms and other tuft trees usually are rare. Crustose lichens and green algae are present, and climbing vines are usually only abundant in extremely humid regions (e.g., Sumatra, Atrato Valley, Columbia).
0112	Submontane	level 4	Within *Tropical Wet Mainly Evergreen Closed Forest* (011). Emergent trees are largely absent and the canopy is relatively even. Forbs are common in the undergrowth. Vascular epiphytes and vines are abundant. E.g., Atlantic slopes of Costa Rica.
0113	Montane	level 4	Within *Tropical Wet Mainly Evergreen Closed Forest* (011). Trees are less than 50 meters tall, have crowns that extend relatively far down the stem, and often have rough bark. Undergrowth abundant, often with ferns, herbs, mosses, and small palms. E.g., Sierra de Talamanca, Costa Rica.
0114	Subalpine	level 4	Within *Tropical Wet Mainly Evergreen Closed Forest* (011). Occurs at elevations above montane forests, with characteristic vegetation, which is dependent on latitude.
0115	Cloud	level 4	Within *Tropical Wet Mainly Evergreen Closed Forest* (011). Trees are gnarled, have rough bark and are rarely greater than 20 meters tall. Tree crowns, branches, and trunks are burdened with epiphytes, mainly chamaephytic bryophytes. Also, the ground is covered with hygromorphic chamaephytes such as *Selaginella* and ferns. E.g., Blue Mountains, Jamaica.
012	Tropical and Subtropical Seasonal	level 3	Within *Mainly Evergreen Closed Forest* (01). Consisting mainly of broad-leaved evergreen trees. Foliage reduction during the dry season is noticeable, often as partial shedding. Transitional between Tropical Wet Forest and Tropical and Subtropical Semi-deciduous.
0121	Lowland	level 4	Within *Tropical and Subtropical Evergreen Seasonal Closed Forest* (012). Consists of fast growing trees, many exceeding 50 meters tall and usually forming an uneven canopy. Undergrowth is sparse, lichen and green algae are present, and climbing vines are absent.
0122	Submontane	level 4	Within *Tropical and Subtropical Evergreen Seasonal Closed Forest* (012). Trees form an even canopy. Forbs are common in the undergrowth. Vascular epiphytes and vines are abundant.
0123	Montane	level 4	Within *Tropical and Subtropical Evergreen Seasonal Closed Forest* (012). Trees are less than 50 meters tall, have crowns that extend relatively far down the stem and have rough bark. There are no tree ferns; instead, evergreen shrubs are most common.

0124	Subalpine	level 4	Within *Tropical and Subtropical Evergreen Seasonal Closed Forest* (012). This forest resembles the Winter-rain Evergreen Broad-leaved Sclerophyllous dry forest and usually occurs above the cloud forest. Trees are mostly evergreen sclerophyllous trees, smaller than 20 meters with little or no undergrowth, few climbing vines, and few epiphytes, except lichens.
013	Tropical and Subtropical Semi-Deciduous	level 3	Within Mainly *Evergreen Closed Forest* (01). Most of the upper canopy trees are drought-deciduous; many of the understory trees and shrubs are evergreen and more or less sclerophyllous. However, evergreen and deciduous woody plants and shrubs are not always separated by layers; they may occur mixed within the same layer, or shrubs may be primarily deciduous and trees evergreen. Nearly all trees have bud protection and leaves without "drip tips." Trees have rough bark, except some bottle trees, which may be present.
0131	Lowland	level 4	Within *Mainly Evergreen Tropical and Subtropical Semi-deciduous Closed Forest* (013). The taller trees may be bottle trees (e.g., *Ceiba*). There are practically no epiphytes present. The undergrowth is composed of shrubs and seedlings. Succulents such as thin-stemmed caespitose cacti may be present. Vines occur occasionally. A sparse layer of herbaceous vegetation may also be present.
0133	Montane and Cloud	level 4	Within *Mainly Evergreen Tropical and Subtropical Semi-deciduous Closed Forest* (013). This forest is similar to a Semi-deciduous Lowland Forest, however, the canopy is lower and covered with xerophytic epiphytes such as *Tillandsia usneoides*.
014	Subtropical Wet	level 3	Within *Mainly Evergreen Closed Forest* (01). Present only locally and in small fragmentary stands, because the subtropical climate typically has a dry season. It usually grades into Tropical Wet Forest (e.g., Queensland, Australia and Taiwan). Some shrubs may grow in the understory. Seasonal temperature change occurs between summer and winter. There is a more pronounced temperature difference between summer and winter than the (Tropical Wet) Montane Forest (0113).
0141	Lowland	level 4	Within *Mainly Evergreen Subtropical Wet Closed Forest* (014). Consists usually of numerous species of fast growing trees, many exceeding 50 meters tall, generally with smooth, often thin bark, some with buttresses. Emergent trees or at least a very uneven canopy often present. Undergrowth is sparse, composed mainly of tree seedlings. Palms and other tuft trees usually are rare. Crustose lichens and green algae are present, and climbing vines are usually only abundant in extremely humid regions.
0142	Submontane	level 4	Within *Mainly Evergreen Subtropical Wet Closed Forest* (014). Emergent trees are largely absent and the canopy is relatively even. Forbs are common in the undergrowth. Vascular epiphytes and vines are abundant.
0143	Montane	level 4	Within *Mainly Evergreen Subtropical Wet Closed Forest* (014). Trees are less than 50 meters tall, have crowns that extend relatively far down the stem, and often have rough bark. Undergrowth abundant, often with ferns, herbs, mosses, and small palms.
0144	Subalpine	level 4	Within *Mainly Evergreen Subtropical Wet Closed Forest* (014). Occurs at elevations above montane forests, with characteristic vegetation, which is dependent on latitude.
0145	Cloud	level 4	Within *Mainly Evergreen Subtropical Wet Closed Forest* (014). Trees are gnarled, have rough bark and are rarely greater than 20 meters tall. Tree crowns, branches, and trunks are burdened with epiphytes, mainly chamaephytic bryophytes. Also, the ground is covered with hygromorphic chamaephytes (e.g., *Selaginella* and herbaceous ferns).
015	Temperate or Subpolar Wet	level 3	Within *Mainly Evergreen Closed Forest* (01). Occurs only in the extremely oceanic, nearly frost-free climates of the southern hemisphere, mainly in Chile. Consisting mostly of truly evergreen hemisclerophyllous trees and shrubs. Rich in epiphytic mosses, liverworts, and lichens that grow on trees, and in ground-rooted herbaceous ferns.
0151	Temperate	level 4	Within *Mainly Evergreen Temperate or Subpolar Wet Closed Forest* (015). Trees are generally greater than 10 meters tall. Vascular epiphytes and vines may be present.

0152	Subpolar	level 4	Within *Mainly Evergreen Temperate or Subpolar Wet Closed Forest* (015). Trees are generally less than 10 meters tall and often have reduced leaf size. There are few vascular epiphytes present. E.g., beech forests of New Zealand.
016	Temperate with Broad-Leaved Deciduous	level 3	Within *Mainly Evergreen Closed Forest* (01). Requires adequate summer rainfall. This is a mixed evergreen-deciduous class. The dominant trees are mainly hemisclerophyllous evergreen trees (more than 50% of the canopy) and shrubs, and the subdominant trees are deciduous broad-leaved trees and shrubs (more than 25% of the canopy). Rich in perennial herbaceous plants. Very few or no vascular epiphytes and vines.
0161	Lowland	level 4	Within *Temperate Deciduous Broad-Leaved Mainly Evergreen Closed Forest* (016). Consists usually of numerous species of fast growing trees, many exceeding 50 meters tall, generally with smooth, often thin bark, some with buttresses. Emergent trees or at least a very uneven canopy often present. Undergrowth is sparse, composed mainly of tree seedlings. Palms and other tuft trees usually are rare. Crustose lichens and green algae are present, and climbing vines are usually only abundant in extremely humid regions.
0162	Submontane	level 4	Within *Temperate Deciduous Broad-Leaved Mainly Evergreen Closed Forest* (016). Emergent trees are largely absent and the canopy is relatively even. Forbs are common in the undergrowth. Vascular epiphytes and vines are abundant.
0163	Montane	level 4	Within *Temperate Deciduous Broad-Leaved Mainly Evergreen Closed Forest* (016). Trees are less than 50 meters tall, have crowns that extend relatively far down the stem, and often have rough bark. Undergrowth abundant, often with ferns, herbs, mosses, and small palms.
0164	Subalpine	level 4	Within *Temperate Deciduous Broad-Leaved Mainly Evergreen Closed Forest* (016). Occurs at elevations above montane forests, with characteristic vegetation, which is dependent on latitude.
017	Winter-Rain Broad-Leaved Sclerophyllous	level 3	Within *Mainly Evergreen Closed Forest* (01). Often understood as Mediterranean, but present also in southwestern Australia, Chile, and other locations. The climate has a pronounced summer drought. Consisting mainly of sclerophyllous evergreen trees and shrubs, most of which have rough bark. There is very little herbaceous undergrowth. No vascular and few non-flowering epiphytes and lichens, but evergreen woody vines are present.
0171	Lowland and Submontane >50m	level 4	Within *Winter-Rain Evergreen Broad-Leaved Sclerophyllous Closed Forest* (017). Dominated by trees over 50 meters tall (at least 50% of the canopy) such as giant eucalyptus (e.g., *Eucalyptus regnans* in Victoria, Australia and *E. diversicolor* in Western Australia).
0172	Lowland and Submontane <50m	level 4	Within *Winter-Rain Evergreen Broad-Leaved Sclerophyllous Closed Forest* (017). Dominated by trees less than 50 meters tall (more than 50% of the canopy). E.g., Californian live-oak forests.
018	Tropical and Subtropical Needle-Leaved	level 3	Within *Mainly Evergreen Closed Forest* (01). Consisting mainly of needle-leaved or scale-leaved evergreen trees (more than 50% of the canopy). Broad-leaved trees may be present. Vascular epiphytes and vines rarely present. Species typical of the tropical/subtropical zone.
0181	Lowland and Submontane	level 4	Within *Tropical and Subtropical Needle-Leaved Mainly Evergreen Closed Forest* (018). E.g., the pine forests of Honduras and Nicaragua.
0182	Montane and Subalpine	level 4	Within *Tropical and Subtropical Needle-Leaved Mainly Evergreen Closed Forest* (018). E.g., the pine forests of the Philippines and southern Mexico.
019	Temperate and Subpolar Needle-Leaved	level 3	Within *Mainly Evergreen Closed Forest* (01). Consisting mainly of needle-leaved or scale-leaved evergreen trees (more than 50% of the canopy), but broad-leaved trees may be present. Vascular epiphytes and vines are rarely present. Species typical of the temperate/subpolar zone.
0191	Giant (> 50m)	level 4	Within *Temperate and Subpolar Needle-Leaved Mainly Evergreen Closed Forest* (019). Dominated by trees (at least 50% of the canopy) greater than 50 meters tall (e.g., *Sequoia* and *Pseudo-tsuga* forest in the Pacific West of North America).

0192	Irregularly Rounded Crowns	level 4	Within *Temperate and Subpolar Needle-Leaved Mainly Evergreen Closed Forest* (019). Dominated by trees 45-50 meters tall (more than 50% of the canopy), with broad, irregularly rounded crowns (e.g., *Pinus* spp.).
0193	Conical Crowns	level 4	Within *Temperate and Subpolar Needle-Leaved Mainly Evergreen Closed Forest* (019). Dominated by trees 45-50 meters tall (more than 50% of the canopy), with conical crowns (like most *Picea* and *Abies*). E.g., California red fir forests.
0194	Cylindrical Crowns	level 4	Within *Temperate and Subpolar Needle-Leaved Mainly Evergreen Closed Forest* (019). Dominated by trees 45-50 meters tall (more than 50% of the canopy), with crowns with very short branches and therefore a narrow cylindrical shape.
02	Mainly Deciduous	level 2	Within *Closed Forest* (0). The majority of trees (more than 50% of the canopy) shed their foliage simultaneously in connection with the unfavorable season (drought or cold).
021	Tropical and Subtropical Drought-Deciduous	level 3	Within *Mainly Deciduous Closed Forest* (02). The unfavorable season is mainly characterized by drought, in most cases by winter-drought. Foliage is shed regularly every year. Most trees have relatively thick, fissured bark.
0211	Broad-Leaved Lowland and Submontane	level 4	Within *Tropical and Subtropical Drought-Deciduous Closed Forest* (021). Practically no evergreen plants in stratum except some succulents. Woody and herbaceous vines and deciduous bottle-trees are present occasionally. Sparse herbaceous vegetation present in the undergrowth. E.g., the broad-leaved deciduous forests of northwestern Costa Rica.
0212	Montane and Cloud	level 4	Within *Tropical and Subtropical Drought-Deciduous Closed Forest* (021). Some evergreen species are present in the understory. Drought resistant epiphytes are present or abundant, often of the bearded form (e.g., *Usnea* or *Tillandsia usneoides*). This formation is not frequent, but well developed. E.g., in northern Peru.
022	Cold-Deciduous with Evergreens	level 3	Within *Mainly Deciduous Closed Forest* (02). The unfavorable season is mainly characterized by winter frost. Deciduous broad-leaved trees are dominant (more than 50% of the canopy), but evergreen species are present (more than 25% of the canopy) as part of the main canopy or the understory. Climbers and vascular epiphytes are scarce or absent.
0221	With Evergreen Broad-Leaved Trees and Climbers	level 4	Within *Cold-Deciduous with Evergreens Closed Forest* (022). Rich in epiphytes, including mosses. Vascular epiphytes may be present at the base of tree stems. Climbing vines may be common on flood plains. Ex. *Ilex aquifolium* and *Hedera helix* in western Europe and *Magnolia* spp. in North America.
0222	With Evergreen Needle-Leaved Trees	level 4	Within *Cold-Deciduous with Evergreens Closed Forest* (022). With evergreen needle-leaved trees such as hemlock (*Tsuga*) and pine (*Pinus*). E.g., the maple-hemlock or oak-pine forests of Northeastern, U.S.A.
023	Cold-Deciduous without Evergreen Trees	level 3	Within *Mainly Deciduous Closed Forest* (02). Deciduous trees are absolutely dominant (more than 75% of the canopy). Evergreen herbs and some evergreen shrubs (less than 2 meters tall) may be present. Climbers insignificant but may be common on flood plains. Vascular epiphytes are absent (except occasionally at the lower base of the tree). Mosses, liverworts and particularly lichens are always present.
0231	Temperate Lowland and Submontane Broad-Leaved	level 4	Within *Cold-Deciduous without Evergreen Trees Closed Forest* (023). Trees are up to 50 meters tall. Epiphytes are primarily algae and crustose lichens. E.g., the Mixed Mesophytic Forest of U.S.A.
0232	Montane and Boreal	level 4	Within *Cold-Deciduous without Evergreen Trees Closed Forest* (023). Trees may be up to 50 meters tall, but in montane or boreal forest normally not taller than 30 meters. Epiphytes are primarily lichens and bryophytes. This class includes lowland or submontane in topographic positions with high atmospheric humidity.
0233	Subalpine and Subpolar	level 4	Within *Cold-Deciduous without Evergreen Trees Closed Forest* (023). Trees are not taller than 20 meters and tree trunks are frequently gnarled. Epiphytes are lichens and bryophytes, and are more abundant than in the Montane or Boreal class (0232). This class often grades into woodland.

03	Extremely Xeromorphic (Dry)	level 2	Within *Closed Forest* (0). Dense stands of trees adapted to dry conditions, such as bottle trees, tuft trees with succulent leaves and stem succulents. Undergrowth has shrubs adapted to dry conditions, succulent perennial herbs and annual and perennial herbaceous plants. Often grades into woodland.
031	Sclerophyllous-Dominated	level 3	Within *Extremely Xeromorphic Closed Forest* (03). There is a predominance of sclerophyllous trees, many of which have bulbous stem bases largely embedded in the soil.
032	Thorn-Dominated	level 3	Within *Extremely Xeromorphic Closed Forest* (03). Species with thorns are dominant (more than 50% of the canopy).
0321	Mixed Deciduous-Evergreen	level 4	Within *Extremely Xeromorphic Thorn-Dominated Closed Forest* (032). Both deciduous and evergreen thorn species are more than 25% of the tree canopy.
0322	Purely Deciduous	level 4	Within *Extremely Xeromorphic Thorn-Dominated Closed Forest* (032). Deciduous thorn species are absolutely dominant (more than 75% of the canopy).
033	Mainly Succulent	level 3	Within *Extremely Xeromorphic Closed Forest* (03). Tree-formed (scapose) and shrub-formed (caespitose) succulents are very frequent (more than 50% of the canopy), but other trees and shrubs adapted to dry conditions are usually present as well.
1	**Woodland**	**level 1**	**Comprised of open stands of trees at least 5 meters tall with crowns not interlocking. The tree canopy covers at least 40% of the ground. Definitions for Mainly Evergreen Woodland, Mainly Deciduous Woodland, and Extremely Xeromorphic Woodland are similar to forest definitions, with sparser stocking of individual trees.**
11	Mainly Evergreen	level 2	Within *Woodland* (1). The canopy is never without green foliage. At least 50% of the trees that reach the canopy are evergreen. Individual trees may shed their leaves.
111	Broad-Leaved	level 3	Within *Mainly Evergreen Woodland* (11). Mainly sclerophyllous broad-leaved trees and shrubs, with no epiphytes.
112	Needle-Leaved	level 3	Within *Mainly Evergreen Woodland* (11). Trees are mainly needle- or scale-leaved (more than 50% of the canopy). Crowns of many trees extend to the base of the stem or are very branchy.
1121	Irregularly Rounded Crowns	level 4	Within *Mainly Evergreen Needle-Leaved Woodland* (112). Dominated by trees (more than 50% of the canopy) with broad, irregularly rounded crowns (e.g., *Pinus*).
1122	Conical Crowns	level 4	Within *Mainly Evergreen Needle-Leaved Woodland* (112). Dominated by trees (more than 50% of the canopy) with conical crowns. Mostly in subalpine areas.
1123	Cylindrical Crowns	level 4	Within *Mainly Evergreen Needle-Leaved Woodland* (112). Dominated by trees (more than 50% of the canopy) with crowns with very short branches and therefore a narrow cylindrical shape (e.g., Picea in the boreal regions).
12	Mainly Deciduous	level 2	Within *Woodland* (1). The majority of trees (more than 50% of the canopy) shed their foliage simultaneously in connection with the unfavorable season (drought or cold).
121	Drought-Deciduous	level 3	Within *Mainly Deciduous Woodland* (12). The unfavorable season is mainly characterized by drought, in most cases by winter-drought. Foliage is shed regularly every year. Most trees have relatively thick, fissured bark.
1211	Broad-Leaved Lowland and Submontane	level 4	Within *Drought-Deciduous Woodland* (121). Practically no evergreen plants in any stratum except some succulents. Woody and herbaceous vines and deciduous bottle-trees are present. Sparse herbaceous vegetation present in the undergrowth.
1212	Montane and Cloud	level 4	Within *Drought-Deciduous Woodland* (121). Some evergreen species are present in the understory. Drought resistant epiphytes are present or abundant, often of the bearded form (e.g., *Usnea* or *Tillandsia usneoides*). This formation is not frequent, but well developed. E.g., in northern Peru.

122	Cold-Deciduous with Evergreens	level 3	Within *Mainly Deciduous Woodland* (12). The unfavorable season is mainly characterized by winter frost. Deciduous broad-leaved trees are dominant (more than 50% of the canopy), but evergreen species are present (more than 25% of the canopy) as part of the main canopy or the understory. Climbers and vascular epiphytes are scarce or absent.
1221	With Evergreen Broad-Leaved Trees and Climbers	level 4	Within *Cold-Deciduous with Evergreens Woodland* (122). Rich in epiphytes, including mosses. Vascular epiphytes may be present at the base of tree stems. Climbing vines may be common on flood plains. *Ilex aquifolium* and *Hedera helix* in western Europe and *Magnolia* spp. in North America are examples of this class type.
1222	With Evergreen Needle-Leaved Trees	level 4	Within *Cold-Deciduous with Evergreens Woodland* (122). With evergreen needle-leaved trees such as hemlock (*Tsuga*) and pine (*Pinus*). E.g., the maple-hemlock or oak-pine woodlands of Northeastern, U.S.A.
123	Cold-Deciduous without Evergreen Trees	level 3	Within *Mainly Deciduous Woodland* (12). Cold-deciduous tree species are absolutely dominant (more than 75% of the canopy). Evergreen herbs and some evergreen shrubs (less than 2 meters tall) may be present. Climbers insignificant but may be common on flood plains. Vascular epiphytes are absent (except occasionally at the lower base of the tree). Mosses, liverworts and particularly lichens are always present. Most frequent in the subarctic region, elsewhere only in swamps or bogs.
1231	Broad-Leaved	level 4	Within *Cold-Deciduous without Evergreen Trees Woodland* (123). Broad-leaved deciduous species are absolutely dominant (more than 75% of the canopy).
1232	Needle-leaved	level 4	Within *Cold-Deciduous without Evergreen Trees Woodland* (123). Needle-leaved deciduous species are absolutely dominant (more than 75% of the canopy).
1233	Mixed	level 4	Within *Cold-Deciduous without Evergreen Trees Woodland* (123). Both broad-leaved and needle leaved deciduous species provide more than 25% of the canopy.
13	Extremely Xeromorphic (Dry)	level 2	Within *Woodland* (1). Stands of trees and shrubs adapted to dry conditions, such as bottle trees, tuft trees with succulent leaves and stem succulents. Undergrowth has shrubs adapted to dry conditions, succulent perennial herbs and annual and perennial herbaceous plants. Woodlands may grade into forests.
131	Sclerophyllous-Dominated	level 3	Within *Extremely Xeromorphic Woodland* (13). There is a predominance of sclerophyllous trees, many of which have bulbous stem bases largely embedded in the soil.
132	Thorn-Dominated	level 3	Within *Extremely Xeromorphic Woodland* (13). Species with thorns are dominant (more than 50% of the canopy).
1321	Mixed Deciduous-Evergreen	level 4	Within *Extremely Xeromorphic Thorn-Dominated Woodland* (132). Both deciduous species and evergreen species are more than 25% of the tree canopy. See definitions of Mainly Evergreen Woodland, class 11 and Mainly Deciduous Woodland (MUC Class 12).
1322	Purely Deciduous	level 4	Within *Extremely Xeromorphic Thorn-Dominated Woodland* (132). Deciduous thorn species are absolutely dominant (more than 75% of the canopy). See definition of Mainly Deciduous Woodland (MUC Class 12).
133	Mainly Succulent	level 3	Within *Extremely Xeromorphic Woodland* (13). Tree-formed (scapose) and shrub-formed (caespitose) succulents are very frequent(more than 50% of the tree canopy), but other trees and shrubs adapted to dry conditions are usually present as well.
2	**Shrubland or Thicket**	**level 1**	**The shrub canopy covers at least 40% of the ground and is composed of matted, clumped or clustered woody plants 0.5 to 5 meters tall.** ***Shrubland:* most of the individual shrubs are not touching each other; often with grass growing between shrubs. Shrublands are also further defined (like Forests and Woodlands) as Evergreen Broad-leaved, Evergreen Needle-leaved, Mainly Deciduous, etc.** ***Thicket:* individual shrub branches are interlocked.**

21	Mainly Evergreen	level 2	Within *Shrubland or Thicket* (2). The canopy is never without green foliage. At least 50% of the shrubs that reach the canopy are evergreen. Individual shrubs may shed their leaves.
211	Broad-Leaved	level 3	Within *Mainly Evergreen Shrubland or Thicket* (21). Evergreen broad-leaved species are dominant (more than 50% of the canopy).
2111	Low Bamboo	level 4	Within *Mainly Evergreen Broad-Leaved Shrubland or Thicket* (211). Bamboo species are dominant. (Lignified creeping graminoid nano- or microphanerophytes).
2112	Tuft-Tree	level 4	Within *Mainly Evergreen Broad-Leaved Shrubland or Thicket* (211). Composed of small trees and woody shrubs. E.g., Mediterranean dwarf palms shrubland or Hawaiian tree fern thicket or shrubland.
2113	Broad-Leaved Hemi-Sclerophyllous	level 4	Within *Mainly Evergreen Broad-Leaved Shrubland or Thicket* (211). Matted or clumped shrubs and plants with large soft leaves (caespitose, creeping or lodged nano- or microphanerophytes). E.g., subalpine *Rhododendron* thickets, or *Hibiscus tiliaeceus* matted thickets of Hawaii.
2114	Broad-Leaved Sclerophyllous	level 4	Within *Mainly Evergreen Broad-Leaved Shrubland or Thicket* (211). Dominated by broad-leaved sclerophyllous shrubs and immature trees (e.g., chapparal or macchia). May often merge with parkland, grassland or heath.
2115	Suffruticose	level 4	Within *Mainly Evergreen Broad-Leaved Shrubland or Thicket* (211). Stand of semi-lignified nanophanerophytes that in dry years may shed part of their shoot systems (e.g., *Cistus* heath).
212	Needle-Leaved or Microphyllous	level 3	Within *Mainly Evergreen Shrubland or Thicket* (21). Dominant species (more than 50% of the canopy) have either needle leaves or small leaves.
2121	Needle-Leaved	level 4	Within *Mainly Evergreen Needle-Leaved or Microphyllous Shrubland or Thicket* (212). Composed of creeping or lodged needle-leaved shrubs (e.g., *Pinus mughus*, "Krummholz").
2122	Microphyllous	level 4	Within *Mainly Evergreen Needle-Leaved or Microphyllous Shrubland or Thicket* (212). Evergreen species have small leaves, (e.g., desert plants) or leaves with a single unbranched vein. Mostly in tropical subalpine belts.
22	Mainly Deciduous	level 2	Within *Shrubland or Thicket* (2). The majority of shrubs (more than 50% of the canopy) shed their foliage simultaneously in connection with the unfavorable season (cold or drought).
221	Drought-Deciduous with Evergreen Woody Plants	level 3	Within *Mainly Deciduous Shrubland or Thicket* (22). Drought-deciduous shrubs are dominant (greater than 50% of the canopy) and are mixed with at least 25% evergreen woody plants. The unfavorable season is mainly characterized by drought.
222	Drought-Deciduous without Evergreen Woody Plants	level 3	Within *Mainly Deciduous Shrubland or Thicket* (22). Drought-deciduous shrubs are absolutely dominant (more than 75% of the canopy). The unfavorable season is mainly characterized by drought.
223	Cold-Deciduous	level 3	Within *Mainly Deciduous Shrubland or Thicket* (22). The unfavorable season is mainly characterized by winter frost. Deciduous shrubs are dominant (more than 50% of the canopy).
2231	Temperate	level 4	Within *Cold-Deciduous Shrubland or Thicket* (223). Composed of dense scrub without, or with very little herbaceous undergrowth. Very few to no cryptogams.
2232	Subalpine and Subpolar	level 4	Within *Cold-Deciduous Shrubland or Thicket* (223). Composed of upright or lodged matted shrubs with great vegetative regeneration capacity and usually covered by snow for at least half a year.
23	Extremely Xeromorphic (Subdesert) Shrubland	level 2	Within *Shrubland or Thicket* (2). Very open stands of shrubs with various adaptations to dry conditions, such as: extremely thickened, hardened foliage; very reduced leaves; green branches without leaves; or succulent stems, some of them with thorns.

231	Mainly Evergreen	level 3	Within *Extremely Xeromorphic Shrubland* (23). The canopy is never without green foliage. At least 50% of the shrubs that reach the canopy are evergreen. In extremely dry years some leaves and shoot portions may be shed.
2311	Purely Evergreen	level 4	Within *Mainly Evergreen Extremely Xeromorphic Shrubland* (231). Composed of broad-leaved mostly sclerophyllous shrubs (e.g., mulga scrub in Australia) leafless green-stemmed plants (e.g. *Retama retam*) or succulents dominated by variously branched stem and leaf succulents.
2312	Semi-Deciduous	level 4	Within *Mainly Evergreen Extremely Xeromorphic Shrubland* (231). May consist of either facultatively deciduous shrubs (e.g., *Atriplex-Kochia* saltbush in Australia and North America) or a combination of evergreen and deciduous shrubs (i.e. evergreen shrubs are dominant, deciduous shrubs cover more than 25%).
232	Mainly Deciduous	level 3	Within *Extremely Xeromorphic Shrubland* (23). The majority of shrubs (more than 50% of the canopy) shed their foliage simultaneously in connection with the unfavorable season (cold or drought).
2321	Without Succulents	level 4	Within *Mainly Deciduous Extremely Xeromorphic Shrubland* (232). Succulents cover less than 25% of the ground.
2322	With Succulents	level 4	Within *Mainly Deciduous Extremely Xeromorphic Shrubland* (232). Succulents cover at least 25% of the ground.
3	**Dwarf-Shrubland or Dwarf- Thicket**	**level 1**	**Shrubs rarely exceed 50 cm in height (sometimes called heaths or heathlike formations). The shrub canopy covers at least 40% of the ground. The shrub cover density distinguishes between Dwarf-Shrubland and Dwarf-Thicket classes.** ***Dwarf-Shrubland*: individual dwarf-shrubs are isolated or in clumps.** ***Dwarf-Thicket*: individual shrub branches are interlocked.**
31	Mainly Evergreen	level 2	Within *Dwarf-Shrubland or Dwarf-Thicket* (3). The canopy is never without green foliage. At least 50% of the shrubs that reach the canopy are evergreen. Individual shrubs may shed their leaves.
311	Dwarf-Thicket	level 3	Within *Mainly Evergreen Dwarf-Shrubland or Dwarf-Thicket* (31). Composed of densely closed dwarf-shrub cover, which dominates the landscape.
3111	Caespitose	level 4	Within *Mainly Evergreen Dwarf-Thicket* (311). Shrub branches stand upright and are often occupied by lichens (foliose). Cushion-shaped mosses, lichens and other herbaceous plants are often found on the ground (e.g., *Calluna* heath).
3112	Creeping	level 4	Within *Mainly Evergreen Dwarf-Thicket* (311). Shrub branches creep along the ground. Variously combined with shrubs (e.g., thallochamaephytes) with branches that may be embedded (e.g., *Loiseleuria* heath).
312	Dwarf-Shrubland	level 3	Within *Mainly Evergreen Dwarf-Shrubland or Dwarf-Thicket* (31). Open or less dense cover of dwarf-shrubs. Shrub canopies are not interlocked. Herbaceous vegetation (i.e. grasses and forbs) covers less than 25% of the ground.
3121	Cushion	level 4	Within *Mainly Evergreen Dwarf-Shrubland* (312). Shrubs are isolated in clumps forming dense cushions and are often thorny (e.g., *Astragalus*- and *Acantholimon* "porcupine"-heath of the East Mediterranean mountains).
313	Mixed Evergreen and Herbaceous Dwarf-Shrubland	level 3	Within *Mainly Evergreen Dwarf-Shrubland or Dwarf-Thicket* (31). Shrub canopies are not interlocked. Evergreen shrubs are mixed with herbaceous vegetation (at least 25% of the ground).
3131	True Evergreen and Herbaceous Mixed	level 4	Within *Mixed Evergreen and Herbaceous Dwarf-Shrubland* (313). True Evergreen individuals do not seasonally shed parts of their shoot systems. E.g., *Nardus Calluna*-heath.
3132	Partial Evergreen and Herbaceous Mixed	level 4	Within *Mixed Evergreen and Herbaceous Dwarf-Shrubland* (313). Many individuals shed parts of their shoot systems during the dry season (e.g., *Phyrgana* in Greece).
32	Mainly Deciduous	level 2	Within *Dwarf-Shrubland or Dwarf-Thicket* (3). The majority of shrubs (more than 50% of the canopy) shed their foliage simultaneously in connection with the unfavorable season (cold or drought).

321	Facultative Drought-Deciduous	level 3	Within *Mainly Deciduous Dwarf-Shrubland or Dwarf-Thicket* (32). Dwarf-shrubs shed their foliage only in extremely dry years.
322	Obligate Drought-Deciduous	level 3	Within *Mainly Deciduous Dwarf-Shrubland or Dwarf-Thicket* (32). Densely closed dwarf-shrubs lose all or at least part of their leaves in the dry season.
3221	Caespitose Dwarf-Thicket	level 4	Within *Obligate Drought-Deciduous Dwarf-Shrubland or Dwarf-Thicket* (322). Shrub branches stand upright and are often occupied by lichens (foliose). Cushion-shaped mosses, lichens and other herbaceous plants are often found on the ground (e.g., *Calluna* heath).
3222	Creeping Dwarf-Thicket.	level 4	Within *Obligate Drought-Deciduous Dwarf-Shrubland or Dwarf-Thicket* (322). Shrub branches creep along the ground. Variously combined with shrubs (i.e. thallochamaephytes) with branches that may be embedded (e.g., *Loiseleuria* heath).
3223	Cushion Dwarf-Shrubland	level 4	Within *Obligate Drought-Deciduous Dwarf-Shrubland or Dwarf-Thicket* (322). Shrubs are isolated in clumps forming dense cushions and are often thorny.
3224	Mixed Dwarf-Shrubland	level 4	Within *Obligate Drought-Deciduous Dwarf-Shrubland or Dwarf-Thicket* (322). Deciduous and evergreen dwarf-shrubs, caespitose herbaceous plants, succulent perennial herbs, and other species intermixed.
323	Cold-Deciduous	level 3	Within *Mainly Deciduous Dwarf-Shrubland or Dwarf-Thicket* (32). Densely closed dwarf-shrubs shed foliage at the beginning of a cold season. Richer in mosses and ferns than the Obligate Drought-deciduous Dwarf Thicket or Shrubland class (322).
3231	Caespitose Dwarf-Thicket	level 4	Within *Cold-deciduous Dwarf-Shrubland or Dwarf-Thicket* (323). Shrub branches stand upright and are often occupied by lichens (foliose). Cushion-shaped mosses, lichens and other herbaceous plants are often found on the ground.
3232	Creeping Dwarf-Thicket	level 4	Within *Cold-deciduous Dwarf-Shrubland or Dwarf-Thicket* (323). Shrub branches creep along the ground; combined with shrubs with branches that may be embedded.
3233	Cushion Dwarf-Shrubland	level 4	Within *Cold-deciduous Dwarf-Shrubland or Dwarf-Thicket* (323). Shrubs are isolated in clumps forming dense cushions and are often thorny.
3234	Mixed Dwarf-Shrubland	level 4	Within *Cold-deciduous Dwarf-Shrubland or Dwarf-Thicket* (323). Deciduous and evergreen dwarf-shrubs, caespitose herbaceous plants, succulent perennial herbs, and other species intermixed.
33	Extremely Xeromorphic (Subdesert) Dwarf-Shrubland	level 2	Within *Dwarf-Shrubland or Dwarf-Thicket* (3). Composed of open formations of dwarf-shrubs, succulents, and herbaceous plants adapted to survive or to avoid a long dry season. Mostly subdesertic.
331	Mainly Evergreen	level 3	Within *Extremely Xeromorphic Dwarf-Shrubland* (33). The canopy is never without green foliage. At least 50% of the shrubs that reach the canopy are evergreen. In extremely dry years some leaves and shoot portions may be shed.
3311	Purely Evergreen	level 4	Within *Mainly Evergreen Extremely Xeromorphic Dwarf-Shrubland* (331). Composed of broad-leaved mostly sclerophyllous shrubs, leafless green-stemmed plants, or succulents dominated by variously branched stem and leaf succulents.
3312	Semi-Deciduous	level 4	Within *Mainly Evergreen Extremely Xeromorphic Dwarf-Shrubland* (331). May consist of either facultatively deciduous shrubs or a combination of evergreen and deciduous shrubs (i.e. evergreen shrubs are dominant, deciduous shrubs cover more than 25%).
332	Mainly Deciduous	level 3	Within *Extremely Xeromorphic Dwarf-Shrubland* (33). The majority of shrubs (more than 50% of the canopy) shed their foliage simultaneously in connection with the unfavorable season (cold or drought).
3321	Without Succulents	level 4	Within *Mainly Deciduous Extremely Xeromorphic Dwarf-Shrubland* (332). Succulents cover less than 25% of the ground.

3322	With Succulents	level 4	Within *Mainly Deciduous Extremely Xeromorphic Dwarf-Shrubland* (332). Succulents cover at least 25% of the ground.
34	Tundra	level 2	Within *Dwarf-Shrubland or Dwarf-Thicket* (3). Slowly growing, low formations, consisting mainly of dwarf-shrubs, graminoids, mosses, liverworts and lichens, found beyond the subpolar tree line. Often showing plant patterns caused by freezing movements of the soil. Except in boreal regions, dwarf-shrub formations above the mountain tree line should not be called tundra, because they are, as a rule, richer in dwarf-shrubs and grasses, and grow taller due to greater solar radiation in lower latitudes.
341	Mainly Bryophyte	level 3	Within *Tundra Dwarf-Shrubland or Dwarf-Thicket* (34). Dominated by mats or small cushions of chamaephytic mosses (more than 50% of the vegetative cover). Groups of dwarf-shrubs are as a rule scattered irregularly and are not very dense. The general aspect is more or less dark green, olive green or brownish.
3411	Caespitose	level 4	Within *Mainly Bryophyte Tundra Dwarf-Shrubland or Dwarf-Thicket* (341). Clumped or clustered dwarf-shrubs are present.
3412	Creeping	level 4	Within *Mainly Bryophyte Tundra Dwarf-Shrubland or Dwarf-Thicket* (341). Creeping or matted dwarf-shrubs are present.
342	Mainly Lichen	level 3	Within *Tundra Dwarf-Shrubland or Dwarf-Thicket* (34). Mats of fruticose lichens dominate (more than 50% of the vegetative cover), giving the formation a more or less pronounced gray aspect. Mostly evergreen, creeping or cushion-shaped dwarf-shrubs are present.
4	**Herbaceous Vegetation**	**level 1**	**Dominated by herbaceous growth of two major types: graminoids and forbs. Graminoids include all herbaceous grasses and grass-like plants such as sedges (*Carex*), rushes (*Juncus*), and cattails (*Typha*). Forbs are broad-leaved herbaceous plants such as clover (*Trifolium*), sunflowers (*Helianthus*), ferns, and milkweeds (*Asclepias*). Total ground coverage must be greater than 60% herbaceous vegetation.**
41	Tall Graminoid	level 2	Within *Herbaceous Vegetation* (4). Plant community consists of dominant grasses over 2 meters tall when flowering or mature (more than 50% of the herbaceous vegetation). Forbs may be present but comprise less than 50% of herbaceous vegetation.
411	With Trees Covering 10-40%	level 3	Within *Tall Graminoid Herbaceous Vegetation* (41). May be with or without shrubs. This is somewhat like a very open woodland with more or less continuous ground cover (over 60%) of tall graminoids.
4110	Trees: Needle-Leaved Evergreen	level 4	Within *Tall Graminoid Herbaceous Vegetation with Trees Covering 10-40%* (411). Needle-leaved evergreen species are greater than 50% of the tree canopy.
4111	Trees: Broad-Leaved Evergreen	level 4	Within *Tall Graminoid Herbaceous Vegetation with Trees Covering 10-40%* (411). Broad-leaved evergreen species are greater than 50% of the tree canopy.
4112	Trees: Broad-Leaved Semi-Evergreen	level 4	Within *Tall Graminoid Herbaceous Vegetation with Trees Covering 10-40%* (411). Trees present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.
4113	Trees: Broad-Leaved Deciduous	level 4	Within *Tall Graminoid Herbaceous Vegetation with Trees Covering 10-40%* (411). Broad-leaved species are greater than 50% of the tree canopy. The area is seasonally flooded. E.g., Northeast Bolivia.
412	With Trees Covering <10%	level 3	Within *Tall Graminoid Herbaceous Vegetation* (41). Grassland with trees covering less than 10% of the ground, with or without shrubs.
4120	Trees: Needle-Leaved Evergreen	level 4	Within *Trees Covering <10% Tall Graminoid Herbaceous Vegetation* (412). Needle-leaved evergreen species are greater than 50% of the tree canopy.
4121	Trees: Broad-Leaved Evergreen	level 4	Within *Trees Covering <10% Tall Graminoid Herbaceous Vegetation* (412). Broad-leaved evergreen species are greater than 50% of the tree canopy.

4122	Trees: Broad-Leaved Semi-Evergreen	level 4	Within *Trees Covering <10% Tall Graminoid Herbaceous Vegetation* (412). Trees present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.
4123	Trees: Broad-Leaved Deciduous	level 4	Within *Trees Covering <10% Tall Graminoid Herbaceous Vegetation* (412). Broad-leaved species are greater than 50% of the tree canopy. The area is seasonally flooded.
4124	Tropical and Subtropical with Trees and Shrubs in Tufts on Termite Nests	level 4	Within *Trees Covering <10% Tall Graminoid Herbaceous Vegetation* (412). Tropical or subtropical tall grassland with trees and/or shrubs growing in tufts on termite nests. Also called termite savannah.
413	With Shrubs	level 3	Within *Tall Graminoid Herbaceous Vegetation* (41). The shrub canopy must cover more than 25% of the ground.
4130	Shrubs: Needle-Leaved Evergreen	level 4	Within *Tall Graminoid Herbaceous Vegetation with Shrubs* (413). Needle-leaved evergreen species are greater than 50% of the shrub canopy.
4131	Shrubs: Broad-Leaved Evergreen	level 4	Within *Tall Graminoid Herbaceous Vegetation with Shrubs* (413). Broad-leaved evergreen species are greater than 50% of the shrub canopy.
4132	Shrubs: Broad-Leaved Semi-Evergreen	level 4	Within *Tall Graminoid Herbaceous Vegetation with Shrubs* (413). Shrubs present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous.
4133	Shrubs: Broad-Leaved Deciduous	level 4	Within *Tall Graminoid Herbaceous Vegetation with Shrubs* (413). Broad-leaved species are greater than 50% of the shrub canopy. The area is seasonally flooded.
4134	Tropical and Subtropical with Trees and Shrubs in Tufts on Termite Nests	level 4	Within *Tall Graminoid Herbaceous Vegetation with Shrubs* (413). Tropical or subtropical tall grassland with trees and/or shrubs growing in tufts on termite nests. Also called termite savannah.
414	With Tuft Plants	level 3	Within *Tall Graminoid Herbaceous Vegetation* (41). The canopy of the tuft plants (usually palms) must cover more than 25% of the ground.
4141	Tropical with Palms	level 4	Within *Tall Graminoid Herbaceous Vegetation with Tuft Plants* (414). Tropical grasslands with palms. E.g., the palm savannas of *Arocomia totai* and *Attalea princeps* north of Santa Cruz de la Sierra, Bolivia.
415	Without Woody Synusia	level 3	Within *Tall Graminoid Herbaceous Vegetation* (41). Grasslands without trees or shrubs.
4151	Tropical	level 4	Within *Tall Graminoid Herbaceous Vegetation Without Woody Synusia* (415). Tropical grassland as in various low-latitude regions of Africa. Often seasonally flooded (e.g., Compos de Varzea of the lower Amazon Valley), (e.g., Papyrus swamps of the upper Nile Valley).
42	Medium Tall Graminoid	level 2	Within *Herbaceous Vegetation* (4). The dominant grasses are 50 cm to 2 m tall when flowering or mature (greater than 50% of the herbaceous vegetation). Forbs may be present but comprise less than 50% of the herbaceous vegetation.
421	With Trees Covering 10-40%	level 3	Within *Medium Tall Graminoid Herbaceous Vegetation* (42). May be with or without shrubs. This is somewhat like a very open woodland with more or less continuous ground cover of medium tall graminoids.
4210	Trees: Needle-Leaved Evergreen	level 4	Within *Medium Tall Graminoid Herbaceous Vegetation with Trees Covering 10-40%* (421). Needle-leaved evergreen species are greater than 50% of the tree canopy.
4211	Trees: Broad-Leaved Evergreen	level 4	Within *Medium Tall Graminoid Herbaceous Vegetation with Trees Covering 10-40%* (421). Broad-leaved evergreen species are greater than 50% of the tree canopy.

4212	Trees: Broad-Leaved Semi-Evergreen	level 4	Within *Medium Tall Graminoid Herbaceous Vegetation with Trees Covering 10-40%* (421). Trees present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.
4213	Trees: Broad-Leaved Deciduous	level 4	Within *Medium Tall Graminoid Herbaceous Vegetation with Trees Covering 10-40%* (421). Broad-leaved species are greater than 50% of the tree canopy. The area is seasonally flooded.
422	With Trees Covering <10%	level 3	Within *Medium Tall Graminoid Herbaceous Vegetation* (42). Grassland with trees covering less than 10% of the ground, with or without shrubs.
4220	Trees: Needle-Leaved Evergreen	level 4	Within *Medium Tall Graminoid Herbaceous Vegetation with Trees Covering <10%* (422). Needle-leaved evergreen species are greater than 50% of the tree canopy.
4221	Trees: Broad-Leaved Evergreen	level 4	Within *Medium Tall Graminoid Herbaceous Vegetation with Trees Covering <10%* (422). Broad-leaved evergreen species are greater than 50% of the tree canopy.
4222	Trees: Broad-Leaved Semi-Evergreen	level 4	Within *Medium Tall Graminoid Herbaceous Vegetation with Trees Covering <10%* (422). Trees present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.
4223	Trees: Broad-Leaved Deciduous	level 4	Within *Medium Tall Graminoid Herbaceous Vegetation with Trees Covering <10%* (422). Broad-leaved species are greater than 50% of the tree canopy. The area is seasonally flooded.
4224	Tropical and Subtropical with Trees and Shrubs in Tufts on Termite Nests	level 4	Within *Medium Tall Graminoid Herbaceous Vegetation with Trees Covering <10%* (422). Tropical or subtropical medium tall grassland with trees and/or shrubs growing in tufts on termite nests. Also called termite savannah.
423	With Shrubs	level 3	Within *Medium Tall Graminoid Herbaceous Vegetation* (42). The shrub canopy must cover more than 25% of the ground.
4230	Shrubs: Needle-Leaved Evergreen	level 4	Within *Medium Tall Graminoid Herbaceous Vegetation with Shrubs* (423). Needle-leaved evergreen species are greater than 50% of the shrub canopy.
4231	Shrubs: Broad-Leaved Evergreen	level 4	Within *Medium Tall Graminoid Herbaceous Vegetation with Shrubs* (423). Broad-leaved species are greater than 50% of the shrub canopy.
4232	Shrubs: Broad-Leaved Semi-Evergreen	level 4	Within *Medium Tall Graminoid Herbaceous Vegetation with Shrubs* (423). Shrubs present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous.
4233	Shrubs: Broad-Leaved Deciduous	level 4	Within *Medium Tall Graminoid Herbaceous Vegetation with Shrubs* (423). Broad-leaved evergreen species are greater than 50% of the shrub canopy. The area is seasonally flooded.
4234	Tropical and Subtropical with Trees and Shrubs in Tufts on Termite Nests	level 4	Within *Medium Tall Graminoid Herbaceous Vegetation with Shrubs* (423). Tropical or subtropical medium tall grassland with trees and/or shrubs growing in tufts on termite nests. Also called termite savannah.
4235	Woody Synusia of Deciduous Thorny Shrubs	level 4	Within *Medium Tall Graminoid Herbaceous Vegetation with Shrubs* (423). Consists of deciduous thorny shrubs covering at least 25% of the ground. E.g., the tropical thorn bush savannah of the Sahel region in Africa with *Acacia tortilis*, *A. senegal* and other species.
424	Open Synusia of Tuft Plants	level 3	Within *Medium Tall Graminoid Herbaceous Vegetation* (42). The canopy of the tuft plants (usually palms) must cover more than 25% of the ground.

4241	Subtropical with Open Palm Groves	level 4	Within *Open Synusia of Tuft Plants Medium Tall Graminoid Herbaceous Vegetation* (424). Medium tall grassland with open groves of palms (e.g., Corrientes, Argentina). Some areas are seasonally flooded (e.g., *Mauritia* palm groves in the Colombian and Venezuelan Ilanos).
425	Without Woody Synusia	level 3	Within *Medium Tall Graminoid Herbaceous Vegetation* (42). Medium tall grasslands without trees or shrubs (less than 25% of the ground).
4251	Mainly Sod Grasses	level 4	Within *Medium Tall Graminoid Herbaceous Vegetation Without Woody Synusia* (425). Perennial, highly branched, creeping grass, which binds the sand or soils with its root system. E.g., St. Augustine grass (*Stenotaphrum secundatum*), the tall-grass prairie in eastern Kansas, or on sandy soil or dunes, such as the communities of *Andropogon hallii* in the Nebraska Sand Hills. In some locations the grassland is wet or flooded most of the year (e.g., Typha swamps). If that is the case classify as a wetland. See MUC class 6.
4252	Mainly Bunch Grasses	level 4	Within *Medium Tall Graminoid Herbaceous Vegetation Without Woody Synusia* (425). Grasses that chiefly grow in tufts forming an irregular textured surface. E.g., the hard tussock (*Festuca novae-zelandiae*) grasslands in New Zealand.
43	Short Graminoid	level 1	Within *Herbaceous Vegetation* (4). The dominant grasses are less than 50 cm tall when flowering or mature (more than 50% of the herbaceous vegetation). Forbs may be present but they comprise less than 50% of the herbaceous vegetation.
431	With Trees Covering 10-40%	level 3	Within *Short Graminoid Herbaceous Vegetation* (43). May be with or without shrubs. This is somewhat like a very open woodland with more or less continuous ground cover of short graminoids.
4310	Trees: Needle-Leaved Evergreen	level 4	Within *Short Graminoid Herbaceous Vegetation with Trees Covering 10-40%* (431). Needle-leaved evergreen species are greater than 50% of the tree canopy.
4311	Trees: Broad-Leaved Evergreen	level 4	Within *Short Graminoid Herbaceous Vegetation with Trees Covering 10-40%* (431). Broad-leaved evergreen species are greater than 50% of the tree canopy.
4312	Trees: Broad-Leaved Semi-Evergreen	level 4	Within *Short Graminoid Herbaceous Vegetation with Trees Covering 10-40%* (431). Trees present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.
4313	Trees: Broad-Leaved Deciduous	level 4	Within *Short Graminoid Herbaceous Vegetation with Trees Covering 10-40%* (431). Broad-leaved species are greater than 50% of the tree canopy. The area is seasonally flooded.
432	With Trees Covering <10%	level 3	Within *Short Graminoid Herbaceous Vegetation* (43). Grassland with trees covering less than 10% of the ground, with or without shrubs.
4320	Trees: Needle-Leaved Evergreen	level 4	Within *Short Graminoid Herbaceous Vegetation with Trees Covering <10%* (432). Needle-leaved evergreen species are greater than 50% of the tree canopy.
4321	Trees: Broad-Leaved Evergreen	level 4	Within *Short Graminoid Herbaceous Vegetation with Trees Covering <10%* (432). Broad-leaved evergreen species are greater than 50% of the tree canopy.
4322	Trees: Broad-Leaved Semi-Evergreen	level 4	Within *Short Graminoid Herbaceous Vegetation with Trees Covering <10%* (432). Trees present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.
4323	Trees: Broad-Leaved Deciduous	level 4	Within *Short Graminoid Herbaceous Vegetation with Trees Covering <10%* (432). Broad-leaved species are greater than 50% of the tree canopy. The area is seasonally flooded.
4324	Tropical and Subtropical with Trees and Shrubs in Tufts on Termite Nests	level 4	Within *Short Graminoid Herbaceous Vegetation with Trees Covering <10%* (432). Tropical or subtropical short grassland with trees and/or shrubs growing in tufts on termite nests. Also called termite savannah.

433	With Shrubs	level 3	Within *Short Graminoid Herbaceous Vegetation* (43). The shrub canopy must cover more than 25% of the ground.
4330	Shrubs: Needle-Leaved Evergreen	level 4	Within *Short Graminoid Herbaceous Vegetation with Shrubs* (433). Needle-leaved evergreen species are greater than 50% of the shrub canopy.
4331	Shrubs: Broad-Leaved Evergreen	level 4	Within *Short Graminoid Herbaceous Vegetation with Shrubs* (433). Broad-leaved evergreen species are greater than 50% of the shrub canopy.
4332	Shrubs: Broad-Leaved Semi-Evergreen	level 4	Within *Short Graminoid Herbaceous Vegetation with Shrubs* (433). Shrubs present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous.
4333	Shrubs: Broad-Leaved Deciduous	level 4	Within *Short Graminoid Herbaceous Vegetation with Shrubs* (433). Broad-leaved species are greater than 50% of the shrub canopy. The area is seasonally flooded.
4334	Tropical and Subtropical with Trees and Shrubs in Tufts on Termite Nests	level 4	Within *Short Graminoid Herbaceous Vegetation with Shrubs* (433). Tropical or subtropical short grassland with trees and/or shrubs growing in tufts on termite nests. Also called termite savannah.
4335	Woody Synusia of Deciduous Thorny Shrubs	level 4	Within *Short Graminoid Herbaceous Vegetation with Shrubs* (433). Consists of deciduous thorny shrubs covering at least 25% of the ground.
434	Open Synusia of Tuft Plants	level 3	Within *Short Graminoid Herbaceous Vegetation* (43). The canopy of the tuft plants (usually palms) must cover more than 25% of the ground.
4341	Subtropical with Open Palm Groves	level 4	Within *Open Synusia of Tuft Plants Short Graminoid Herbaceous Vegetation* (434). Short grassland with open groves of palms. The canopy of palms must cover more than 25% of the ground.
435	Mainly Bunch Grasses with Woody Synusia	level 3	Within *Short Graminoid Herbaceous Vegetation* (43). Grasses that grow in tufts, with woody plants interspersed.
4351	Tropical Alpine with Tuft Plants	level 4	Within *Mainly Bunch Grasses with Woody Synusia Short Graminoid Herbaceous Vegetation* (435). This grassland often contains *Espeletia, Lobelia, Senecio,* microphyllous dwarf-shrubs, and cushion plants (often with woolly leaves). Above the timberline in low latitudes. E.g., Paramo and related vegetation types without snow in the alpine regions of Kenya, Colombia, Venezuela, etc.
4352	Tropical Alpine without Tuft Plants	level 4	Within *Mainly Bunch Grasses with Woody Synusia Short Graminoid Herbaceous Vegetation* (435). Similar to Tropical Alpine with Tuft Plants (4351) but very open and without tuft plants. In these grasslands there is frequent nocturnal snowfall (though the snow is gone by 9 a.m.). E.g., the Super-Paramo (i.e. above Paramo) of J. Cuatrescasas.
4353	Tropical and Subtropical Alpine with Open Stands of Evergreens	level 4	Within *Mainly Bunch Grasses with Woody Synusia Short Graminoid Herbaceous Vegetation* (435). This grassland may also have deciduous shrubs and dwarf shrubs. E.g., Puna south of Oruro, Bolivia.
4354	With Dwarf Shrubs	level 4	Within *Mainly Bunch Grasses with Woody Synusia Short Graminoid Herbaceous Vegetation* (435). Consists of bunch grass with varying coverage of dwarf shrubs. Cushion plants may also grow in this grassland, and may be locally more important than the dwarf-shrubs. E.g., Puna south of Oruro, Bolivia.
436	Without Woody Synusia	level 3	Within *Short Graminoid Herbaceous Vegetation* (43). Short grasslands without trees or shrubs.

4361	Short-Grass Communities	level 4	Within *Short Graminoid Herbaceous Vegetation Without Woody Synusia* (436). These communities may fluctuate in structure and floristic composition due to greatly fluctuating precipitation of the semi-arid climate. E.g., short-grass (*Bouteloua gracilis* and *Buchloe dactyloides*) prairie of eastern Colorado.
4362	Bunch-Grass Communities	level 4	Within *Short Graminoid Herbaceous Vegetation Without Woody Synusia* (436). E.g., blue tussock (*Poa cloensoi*) communities of New Zealand, and alpine dry Puna with *Festuca orthophylla* of northern Chile and southern Bolivia.
437	Short to Medium Tall Mesophytic Communities	level 3	Within *Short Graminoid Herbaceous Vegetation* (43). Plants growing in or adapted to a moderately moist environment.
4371	Sod Grass Communities	level 4	Within *Short to Medium Tall Mesophytic Communities Short Graminoid Herbaceous Vegetation* (437). The grassland is often rich in forbs, and occurs in lower altitudes with a cool, humid climate in North America and Eurasia. Many plants may remain at least partly green during the winter, even below the snow in the higher latitudes.
4372	Alpine and Subalpine Meadows	level 4	Within *Short to Medium Tall Mesophytic Communities Short Graminoid Herbaceous Vegetation* (437). These grasslands are usually moist much of the summer due to snow melt water. May be rich in forbs (e.g., Olympic Peninsula, Washington); rich in dwarf-shrubs (e.g., the Rocky Mountains of Colorado); snow-bed communities rich in small forbs and/or forb-like dwarf-shrubs (e.g., *Salix herbacea*); or avalanche meadows, occurring as narrow strips of grassland between forests on steep slopes of high mountains where avalanches, descending annually in spring, prevent forest growth.
44	Forb Vegetation	level 2	Within *Herbaceous Vegetation* (4). Broad-leaved herbaceous plants dominate the plant community, such as clover, sunflowers (*Helianthus*), ferns, and milkweeds (*Asclepias*) (all plants except grasses). Forbs cover at least 50% of the herbaceous area. Grasses may be present but often less than (often much less than) 50%.
441	Tall Communities	level 3	Within *Forb Herbaceous Vegetation* (44). The dominant forb growth forms are more than 1 meter tall when fully developed.
4411	Fern Thickets	level 4	Within *Tall Forb Communities Herbaceous Vegetation* (441). Ferns occur sometimes in nearly pure stands, especially in humid climates (e.g., *Pteridium aquilinum*).
4412	Mainly Annual	level 4	Within *Tall Forb Communities Herbaceous Vegetation* (441). Annual forbs, which germinate in the beginning and die at the end of each growing season, are the dominant form (greater than 50% of forb vegetation).
4413	Mainly Perennial Flowering Forbs and Ferns	level 4	Within *Tall Forb Communities Herbaceous Vegetation* (441). Some part of the plant is alive all year round.
442	Low Communities	level 3	Within *Forb Herbaceous Vegetation* (44). These communities are dominated by forbs less than 1 meter tall when fully developed.
4421	Mainly Perennial Flowering Forbs and Ferns	level 4	Within *Low Forb Communities Herbaceous Vegetation* (442). Some part of the plant is alive all year round.

4422	Mainly Annual	level 4	Within *Low Forb Communities Herbaceous Vegetation* (442). Annual forbs, which germinate in the beginning and die at the end of each growing season, are the dominant form (greater than 50% of forb vegetation). There are several types of low annual forbs: *Ephemeral forb communities in tropical and subtropical regions*: Forbs grow with very little precipitation where, from autumn to spring, clouds moisten vegetation and soil. The dry season aspect is desert-like. E.g., the coastal hills of Peru and northern Chile *Ephemeral or episodical forb communities of arid regions*: The "flowering desert" consists of mostly fast growing forbs, sometimes concentrated in depressions where water can accumulate in shrub or dwarf shrub formations of arid regions. E.g., the Sonoran Desert.
5	**Barren Land**	**level 1**	**Land with less than 40% vegetative cover. Barren land has a limited ability to support life, and is usually made up of thin soil, sand, or rocks.**
51	Dry Salt Flats	level 2	Occur on flat floored bottoms of interior desert basins. High concentrations of salts are present due to extensive water evaporation.
52	Sandy Areas	level 2	Accumulations of sand/gravel (e.g., beaches or dunes).
53	Bare Rock	level 2	Exposed bedrock, desert pavement, scarps, talus slides, volcanic material, rock glaciers and other accumulations of rock without vegetative cover.
54	Perennial Snowfields	level 2	Accumulations of snow and ice that did not entirely melt during the previous summer, occurring where the daily average temperature is 0°C (32°F) in the warmest summer months.
55	Glaciers	level 2	Snow compacted into firn and finally to ice under weight of successive annual accumulations. Re-frozen melt water contributes to increasing density of the glacial ice mass. All glaciers exhibit evidence of present or past motions (moraines, crevasses, etc.).
56	Other	level 2	Dirt, gravel, other loose rock, etc.
6	**Wetland**	**level 1**	**Marshes, swamps, bogs and other types of wetlands that are periodically or constantly saturated during the growing season. This periodic or constant saturation produces soils with special chemical characteristics and vegetation specifically adapted to wet conditions. The area must have at least 40% vegetative cover to be classified as a wetland.**
61	Riverine	level 2	Wetlands adjacent to a fresh water river channel (riparian wetlands).
62	Palustrine	level 2	Wetlands dominated by trees, shrubs, persistent emergents (plants), mosses, lichens, etc. The wetlands surround water that is less than 1 hectare in size, has no active channel or tide, is less than 2 meters deep, and has low salinity. The water should be included as part of the wetland.
63	Estuarine	level 2	Wetlands occurring adjacent to a tidal channel, or in and adjacent to the intertidal zone. An estuary is a water passage where the tide meets the current of a stream. Deepwater tidal habitats and adjacent tidal wetlands are usually semi-enclosed by land but have open, partially obstructed, or sporadic access to ocean water (at least occasionally diluted by freshwater runoff from the land).
64	Lacustrine	level 2	Wetlands surrounding open water (e.g., ponds and lakes) that are greater than 1 hectare in size and greater than 2 meters deep.
7	**Open Water**	**level 1**	**Lakes, ponds, rivers and oceans. The surface of the land is continually submerged by water greater than 2 meters deep and at least one hectare in size; or continually submerged in an actively flowing channel or subtidal zone. Water should cover greater than 60% of the area.**

71	Freshwater	level 2	Lakes, ponds, and rivers with low salinity.
72	Marine	level 2	Open ocean overlying the continental shelf or an actively flowing tidal channel.
8	**Cultivated Land**	**level 1**	**The ground is covered by greater than 60% non-native cultivated species (e.g., agricultural crops, cultivated short grasses, and lawns) and usually can be distinguished by the regular geometric patterns created by the lawns and fields.**
81	Agriculture	level 2	Land is used for growing crops, orchards, horticulture, feeding livestock, and other agriculture.
811	Row Crop and Pasture	level 3	Examples include corn, wheat, cow pastures, fallow fields, cultivated cranberry bogs, and rice fields.
812	Orchard and Horticulture	level 3	Examples include apple orchards, vineyards, and tree nurseries.
813	Confined Livestock Feeding	level 3	These areas are found on large farms and are used for feeding beef cattle, dairy cows (with confined feedlots), hogs and poultry.
814	Other Agriculture	level 3	Examples include corrals and breeding and training facilities on horse farms.
82	Non-Agriculture	level 2	Land is used for parks, playing fields, cemeteries, and golf courses.
821	Parks and Athletic Fields	level 3	Examples include baseball diamonds, soccer fields, play grounds, and parks.
822	Golf Courses	level 3	Golf Courses
823	Cemeteries	level 3	Cemeteries
824	Other Non-Agriculture	level 3	Any other non-agricultural cultivated areas that do not fit into classes 821, 822 or 823 (parks and playing fields, golf courses, or cemeteries).
9	**Urban**	**level 1**	**Areas developed for residential, commercial, industrial, or transportation uses. Must be greater than 40% urban land cover.**
91	Residential	level 2	Greater than 50% of the urban land cover consists of residential property (e.g., apartments, private dwellings)
92	Commercial and Industrial	level 2	Greater than 50% of the urban land cover consists of commercial or industrial property (e.g., businesses, factories, warehouses)
93	Transportation	level 2	Greater than 50% of the urban land cover consists of transportation routes (e.g., roads, highways, railroads, and airport runways).
94	Other	level 2	At least 50% of the urban land cover consists of developed areas that do not fit into residential, commercial, or transportation categories.

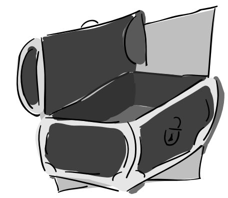
Miscellaneous Definitions	
Annual Plant	Live and grows for only one year or season.
Aspect	View or appearance; a side facing a particular direction.
Boreal	Also called cold temperate zone has a climate with cool wet summers and cold winters lasting more than six months.

Bryophyte	Non-flowering plants (mosses & liverworts) characterized by rhizoids rather than true roots.
Buttresses	Flanges of tissue protruding from the trunk of a tree, tapering outward at the base to give support. Common among large tropical trees.
Caespitose	Arranged or combined in a thick mat or clumps, having a low stem forming a dense turf or sod, growing in clusters.
Canopy	Uppermost layer of vegetation detected by satellite sensors.
Chamaephyte	A perennial plant that has its winter buds placed very close to the soil surface.
Cold-Deciduous	Plants that shed leaves during the cold season.
Crustose Lichens	Lichens that are encrusting. E.g., *Caloplaca saxicola*.
Cultivated Land	Landscaped yards, playing fields, cemeteries, golf courses, and other cultivated vegetated areas should be classified as cultivated land (class 8) if non-native cultivated species is greater than 60% coverage. If the buildings, roads and unnatural structures (bridges, etc.) cover greater than 40% of the land, the area should be classified as urban. If wooded residential neighborhoods have greater than 40% trees covering the ground, the area would be considered forest or woodlands (see classes 0 and 1). If it is difficult to decide upon a cover type, try to determine what the satellite would see. Compare similar areas with the satellite image you receive of your school's location.
Deciduous	Vegetation that sheds its leaves at the end of the growing period or in association with the unfavorable season (drought, cold).
Drip Tips	Extended slender tips of tropical leaves that allow water to roll off the leaf surface.
Drought-Deciduous	Plants that shed their leaves during the dry season.
Emergent	Aquatic plant with the lower part submerged and the upper part extending above the water.
Epiphytes	Plants not connected with the soil, that grow on another plant (upon which it depends for mechanical support) but not for receiving food and water from it, such as certain orchids or ferns.
Facultative	Organisms able to live and thrive under more than one set of conditions.
Firn	Snow that has been partially consolidated, or compacted, by thawing and freezing but not yet converted to glacial ice.
Forb	A broad-leaved herbaceous plant other than a grass such a clover, sunflowers, ferns, and milkweeds.
Fruticose Lichens	Lichens which appear shrubby or hair-like, especially in form.
Graminoid	Grasses and grass-like plants.
Herbaceous	Pertaining to or characteristic of an herb as distinguished from a woody plant. Vascular plant rooted in the ground with foliage that dies back annually. The meristem (stem growth tip) is located just above or below the ground.
Hygromorphic	The form of the plant is altered due to changes in moisture in the plant. E.g., hygromorphic chamaephytes *Selaginella* and herbaceous ferns.
Hemisclerophyllous	Vegetation with slightly thickened foliage, with large soft leaves, that is resistant to water loss. E.g., subalpine *Rhododendron* thickets, or *Hibiscus tiliaceus* matted thickets of Hawaii.
Lichen	Plant made up of an alga and a fungus living in a symbiotic relationship. Specifically, any of a numerous plants consisting of a fungus, usually of the class *Ascomycetes*, in close combination with certain of the green or blue-green algae, characteristically forming a crustlike, scaly, or branching growth on rocks or tree trunks.

Lignified	Woody, hardened. Has formed or turned into wood through the formation and deposit of lignin in the cell walls.
Lowland	An area of land that is low in relation to the surrounding country. It may be necessary to consult local resources to determine the specific classification. Vegetation will vary depending on both the latitude and the altitude.
Mesophytic	Growing in, or adapted to, a moderately moist environment.
Microphanerophytes	Small flowering plants.
Microphyllous	Having small leaves with a single unbranched vein (e.g., desert plants).
Montane	Of, growing in, or inhabiting mountain areas. It may be necessary to consult local resources to determine the specific classification. Vegetation will vary depending on both the latitude and the altitude.
Nanophanerophytes	Very small flowering plants.
Obligate	Organisms restricted to a particular condition of life (that condition is essential for survival).
Overstory	Uppermost layer of vegetation detected by satellite sensors.
Perennial Plant	Has a life span of more than two years.
Polar	In polar climates, the mean temperature of the warmest month is below 10°C and there is low precipitation distributed over the entire year. There is a short, wet, nightless summer and a very long, cold, dark winter. Generally, the climate is too cold to support the growth of trees.
Saturated	Soaked with moisture - the maximum water holding capacity of a soil.
Scapose	Having a leafless flower stalk growing directly from the ground. E.g., agave/century plant.
Sclerophyllous	Vegetation with thickened, hardened foliage that is resistant to water loss (sclerophylly). E.g., plants of the chapparal (semi-arid Mediterranean) such as toyon, ironwood, manzanita, coyote bush, mountain mahogany, and black sage.
Subalpine	Of, designating, or growing or living in mountainous regions just below the timberline. It may be necessary to consult local resources to determine the specific classification. Vegetation will vary depending on both the latitude and the altitude.
Submontane	Located under or at the base of a mountain or mountain range. It may be necessary to consult local resources to determine the specific classification. Vegetation will vary depending on both the latitude and the altitude.
Subpolar	Transitional between the cold temperate zone and the polar zone. It may be necessary to consult local resources to determine the specific classification. Vegetation will vary depending on both the latitude and the altitude.
Subtropical	From the edge of the tropical zone toward the poles, in the region of the descending air masses, which get warmer as it descends and becomes very dry. Rainfall is very low, and the daytime temperatures are very high because of intense solar radiation. In the winter months, however, the temperature may sink to zero at night as a result of the greater net loss of heat energy in outgoing radiation. This is the hot desert zone.
Succulent	Having thickened, juicy, fleshy tissues (leaves or stems), more or less soft in texture, that conserve moisture. E.g., a sedum or a cactus.
Suffruticose	Has a woody stem or base and is somewhat shrubby.
Synusia	A layer or stratum of a community. A structural unit of a major ecological community characterized by relative uniformity of life form or of height and usually constituting a particular stratum of that community.

Temperate	Temperate zones show greater seasonal temperature changes and can be broken down as follows: *Warm temperate*: mild or no winter and extremely wet, especially in summer. *Typical temperate*: cold, short winters or a winter free of frost and with very cool summers (near the ocean) (e.g., central European or coastal northeastern U.S.A). *Arid temperate*: large temperature contrasts between summer and winter, and little precipitation. *Boreal or cold temperate*: cool wet summers and cold winters lasting more than six months.
Tropical	Lies 40 degrees to the north and south of the equator. A certain seasonal variation in the mean daily temperature is noticeable. Rainfall reaches a maximum in the summer, with a dry season in the cool months. The duration of the cool season increases as the distance from the equator becomes greater, and at the same time the annual rainfall decreases.
Understory	Layer of vegetation that grows beneath the overstory consisting of smaller trees and shrubs.
Wet	Vegetation or environments capable of withstanding or thriving in the presence of much rain.
Xeromorphic	Climatic conditions favorable for the development of vegetation that is adapted to, thrives in, or tolerates an environment that is poor in available moisture.
Xerophyte	A plant which is adapted to and thrives in dry conditions.

Glossary



Accuracy
How close a measurement is to a standard value of that measurement

Assessment
Evaluation of the value of an object

Biogeochemical
Refers to the chemical interactions between the living ("bio") and physical ("geo") components of the Earth system, as in biogeochemical cycles of carbon, nitrogen, etc.

Biomass
The dry weight of vegetation above a unit area of ground, often reported as grams (dry weight) per square meter

Biome
A major ecological community type (as grassland or desert)

Biometry
The process of making biological measurements

Biosphere
The living component of the Earth system, along with the gaseous (atmosphere), liquid (hydrosphere), and solid (geosphere) components

Canopy Cover
The amount of canopy foliage above a given portion of ground is the canopy cover. This will determine the amount of sunlight that reaches that portion of ground.

Catastrophic
Used to describe a sudden, violent event

Characteristics
A distinguishing feature

Classification
Sorting a group of items into well-defined and distinct subsets according to specific criteria

Clinometer
A clinometer is an instrument for measuring the angle of a change in height or elevation.

Criteria
Decision rules that are used to determine into which subset an item is placed during a classification

Deciduous
Refers to trees or shrubs that lose their leaves every year

Default
A preset value that a computer uses or an action that it takes unless it is told otherwise

Densiometer
A device for determining the percentage of canopy closure in a wooded environment

Dichotomous
This is a branching decision tree (decoder) characterized by successive forking into two approximately equal and contradictory divisions, which ultimately leads to only one correct outcome.

Difference/Error Matrix
A graphic method of comparing two data sets for validation

Dominant
A plant or animal that, due to its large numbers or size, influences the conditions of an area and determines what other plants or animals can live there

Ecosystem
System formed by the interactions of a community of living things with its environment

Equatorial
Near the equator

Evapotranspiration
The return of water to the atmosphere by evaporation (from solar energy) and transpiration (plant activity.)

Glossary
List of terms in a special subject with their definitions

Genus (pl. Genera)
This is an inclusive category whose species have more characteristics in common with each other than with species of other genera. Genera, therefore, are collections of closely related species.

Geosphere
The solid component of the Earth system; e.g. rocks, soil, etc.

Gradient
The rate of change in a measured quantity over space or time

Graminoid
Grass-like vegetation

Ground Cover
The amount of ground-level vegetation covering a given area. (For the GLOBE program, "ground level" is defined as "below the observer's knees." Ground cover is expressed as a percentage. E.g. 30% ground cover means that, viewed from above, 30% of the ground surface is obscured by ground-level vegetation.

Herbaceous
A plant or plant part that is not woody

Hierarchical
Having the characteristics of a system of objects ranked one above the other

Homogeneous
Composed of parts that are all the same kind, in this case, the same land cover type

Hydrosphere
The liquid component of the Earth system; e.g. oceans, lakes, rivers, etc.

Iterative
To do something over again or repeatedly

Magnetic North
The direction the compass needle points, rather than true north which is a geographic place

Metadata
Any additional information that cannot be expressed in the measurement data such as historical information, weather conditions, weather effects, and other observations

Methodology
A set of procedures or a planned way of doing this investigation

Multitemporal
Viewed from more than one point in time

NOAA
The National Oceanic and Atmospheric Administration.

Perennating Organs
Parts of plants that live over from one season to another (tubers, rhizomes)

Perturbations
A disturbance in the normal functioning of a system

Phenology
The study of changes over time in an environmental setting

Photointerpretation
The production of a land cover map or identification of specific features by visual inspection of an aerial photo or satellite image

Photosynthetic Potential
The maximum amount of biomass that can be produced in an area

Physiological
Characteristic of, or appropriate to, an organism's healthy or normal functioning

Pixels
The smallest element of an image

Precise
Exact in measuring

Primary Productivity
The rate at which organic material is produced by photosynthesis at a given location. Often represented as grams (dry weight) of Carbon per m^2 per year.

Protocol
A plan for carrying out a scientific study

Sediment
Matter that settles to the bottom eventually but can be carried along in a water body or the air until then

Senescence
The plant growth phase from full maturity to death that is characterized by a loss in dry weight

Spatial

Having to do with space

Species

This is a group of individual plants/ animals that is fundamentally alike.

TM

Thematic Mapper. Carried aboard the Landsat 4 and 5 satellites, this instrument is designed to study surface features in 7 bands covering the visible through thermal infrared regions with a pixel resolution of 30 m in 6 bands and 120 m in the thermal infrared band.

Topographic Map

Map showing detailed features and contour lines of an area

Urban

Areas developed for residential (ex. houses, apartments), commercial (ex. stores), industrial (ex. factories) or transportation (ex. roads) uses

Validation Data

Data necessary to assess the accuracy of a land cover map produced by manual or electronic means.

Variation

A different form of something